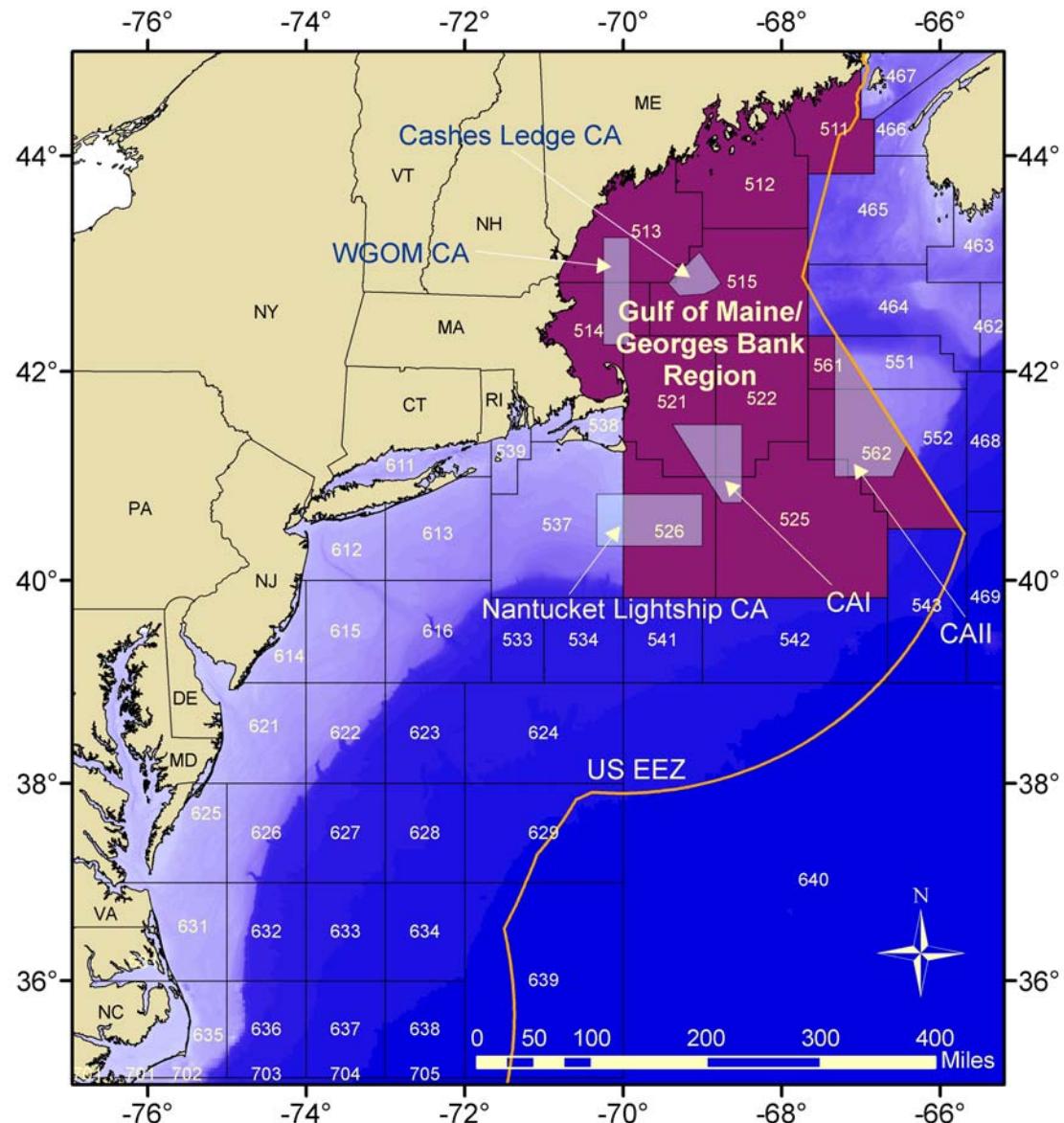


# Atlantic Halibut (*Hippoglossus hippoglossus*)

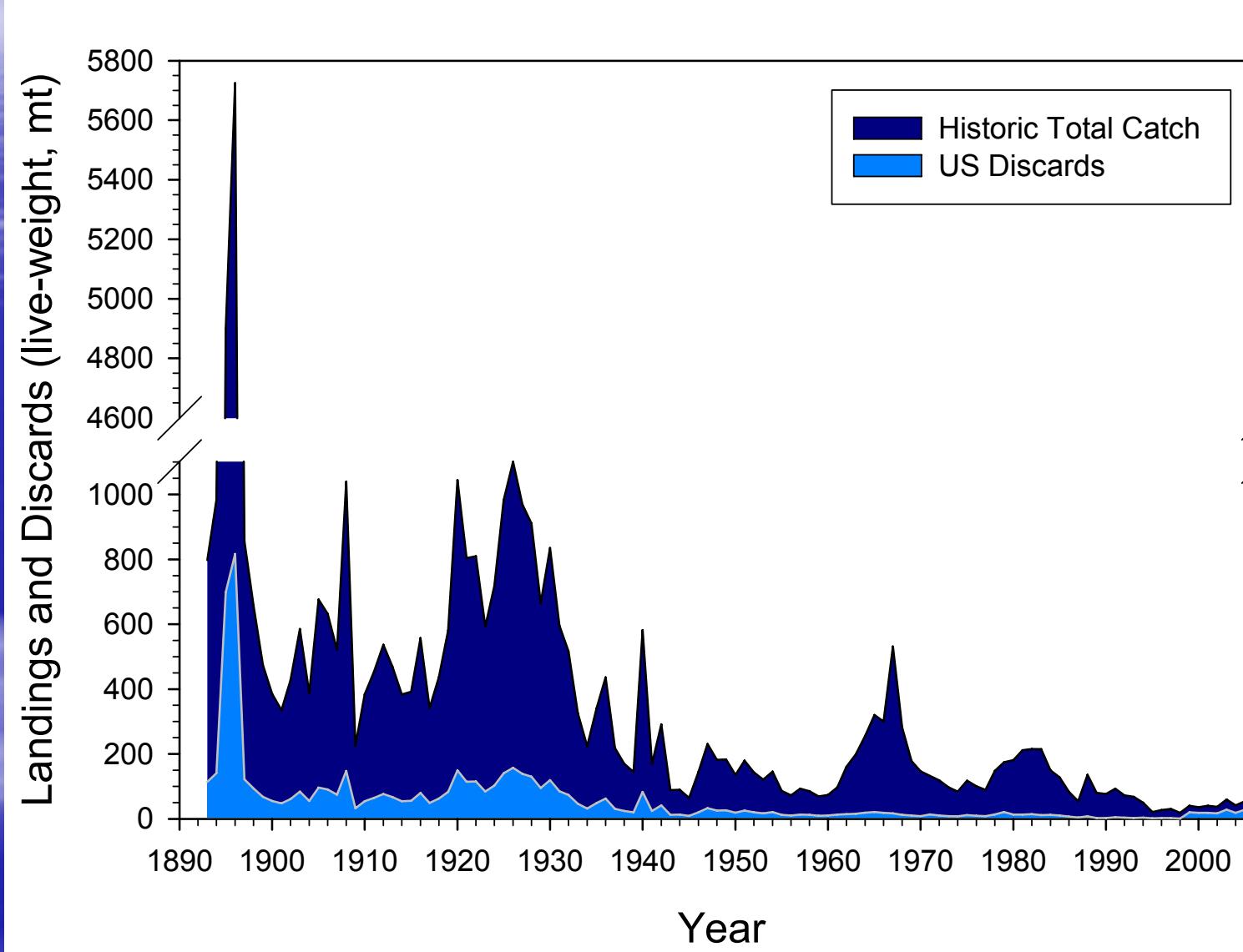
Draft Presentation  
For Peer Review Only.  
Does not represent  
final NOAA Decision/Policy.  
5/01/08



Laurel Col and Chris Legault  
Northeast Fisheries Science Center



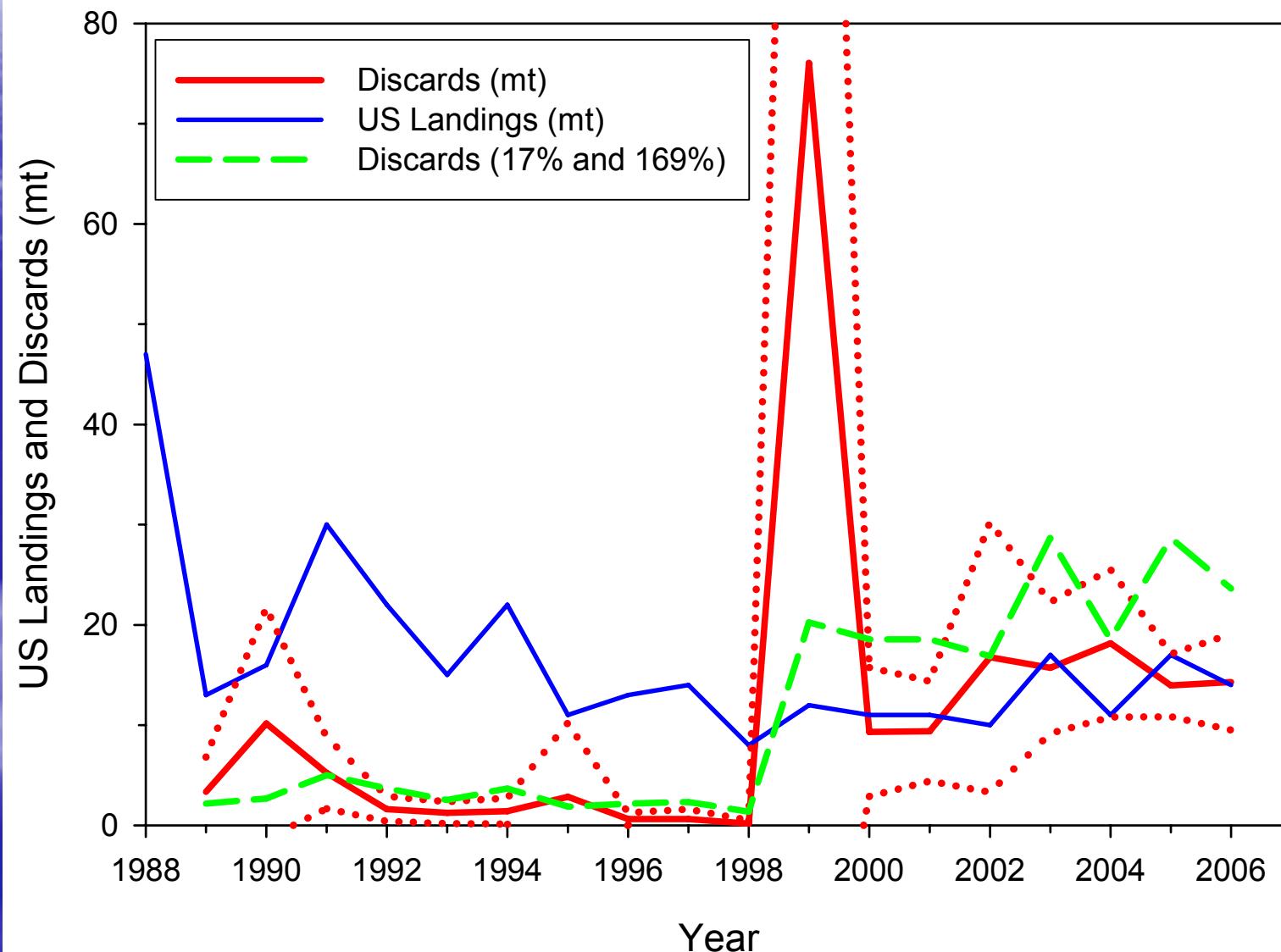
# Atlantic Halibut Commercial Catch



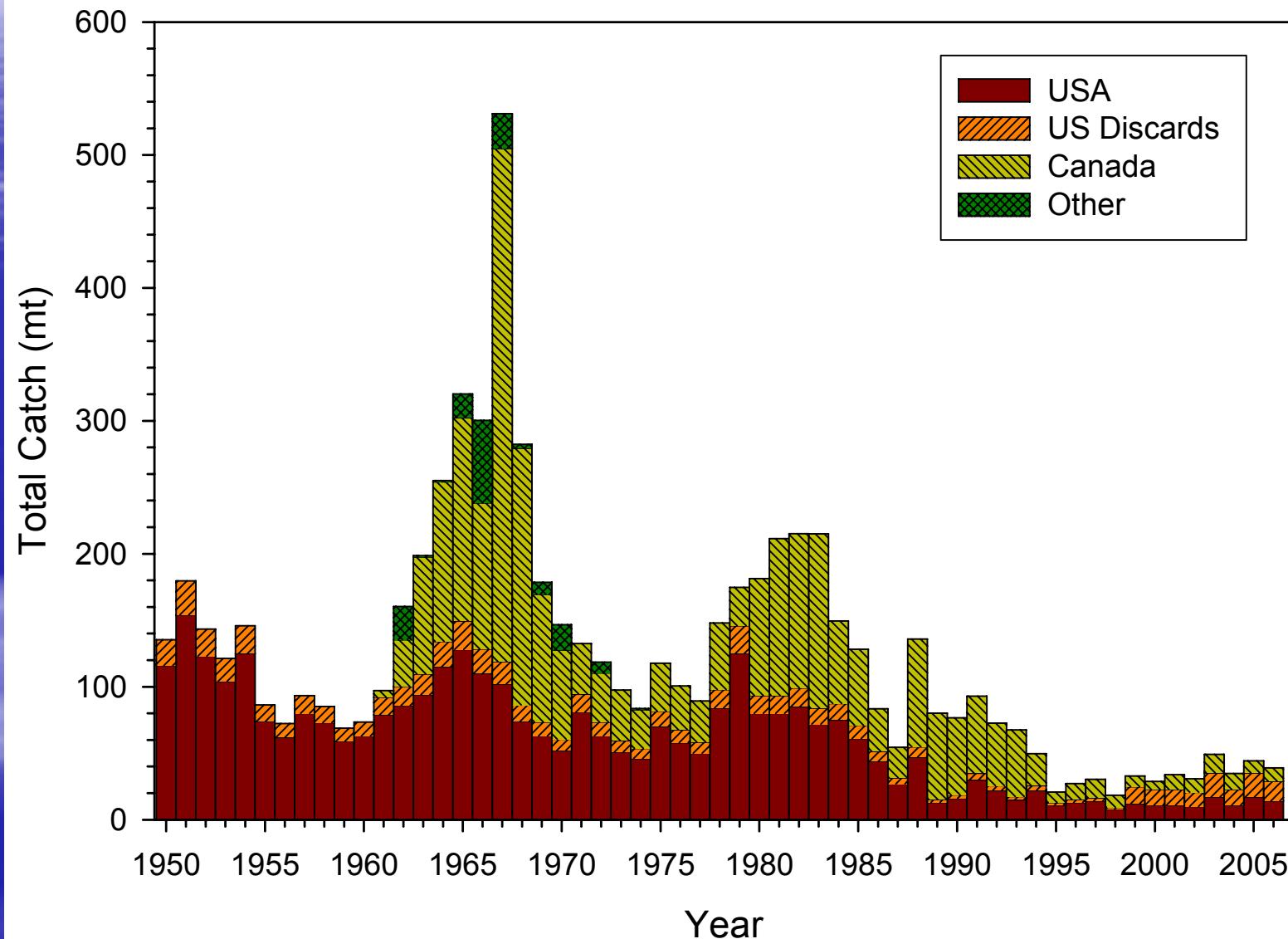
# Atlantic Halibut US Commercial Discards

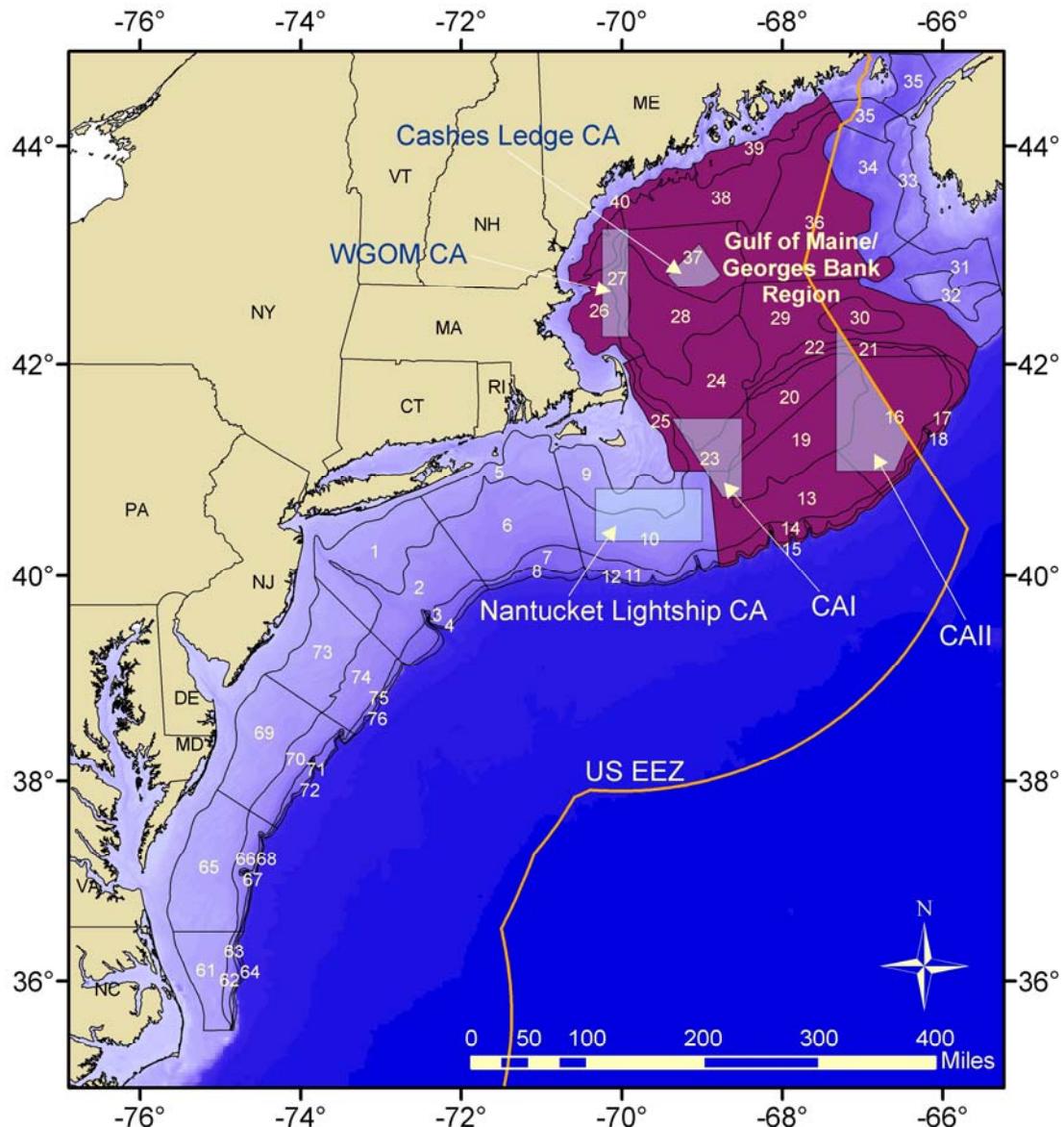
Year	US Discards	cv	# Observed Tows with Discarded Halibut	US Landings	Average Discards	Total US Catch
1989	3.36	0.52477	25	13	2	15
1990	10.17	0.57843	22	16	3	19
1991	5.22	0.34798	48	30	5	35
1992	1.62	0.39357	17	22	4	26
1993	1.26	0.44447	11	15	2	17
1994	1.40	0.47438	8	22	4	26
1995	2.85	1.31873	12	11	2	13
1996	0.63	0.49146	4	13	1989-1998 Average	2
1997	0.62	0.78836	11	14	Discards/Landings=	2
1998	0.16	1.0139	1	8	0.166	1
1999	76.06	0.70184	4	12		20
2000	9.31	0.35247	30	11		19
2001	9.38	0.27133	22	11		19
2002	16.76	0.41048	44	10		17
2003	15.72	0.21205	123	17		29
2004	18.15	0.2071	182	11	1999-2006 Average	19
2005	13.95	0.11444	533	17	Discards/Landings=	29
2006	14.29	0.17081	243	14	1.686	38

## Atlantic halibut US landings (mt) and discards (mt with 95% CI) from combined ratio estimation.



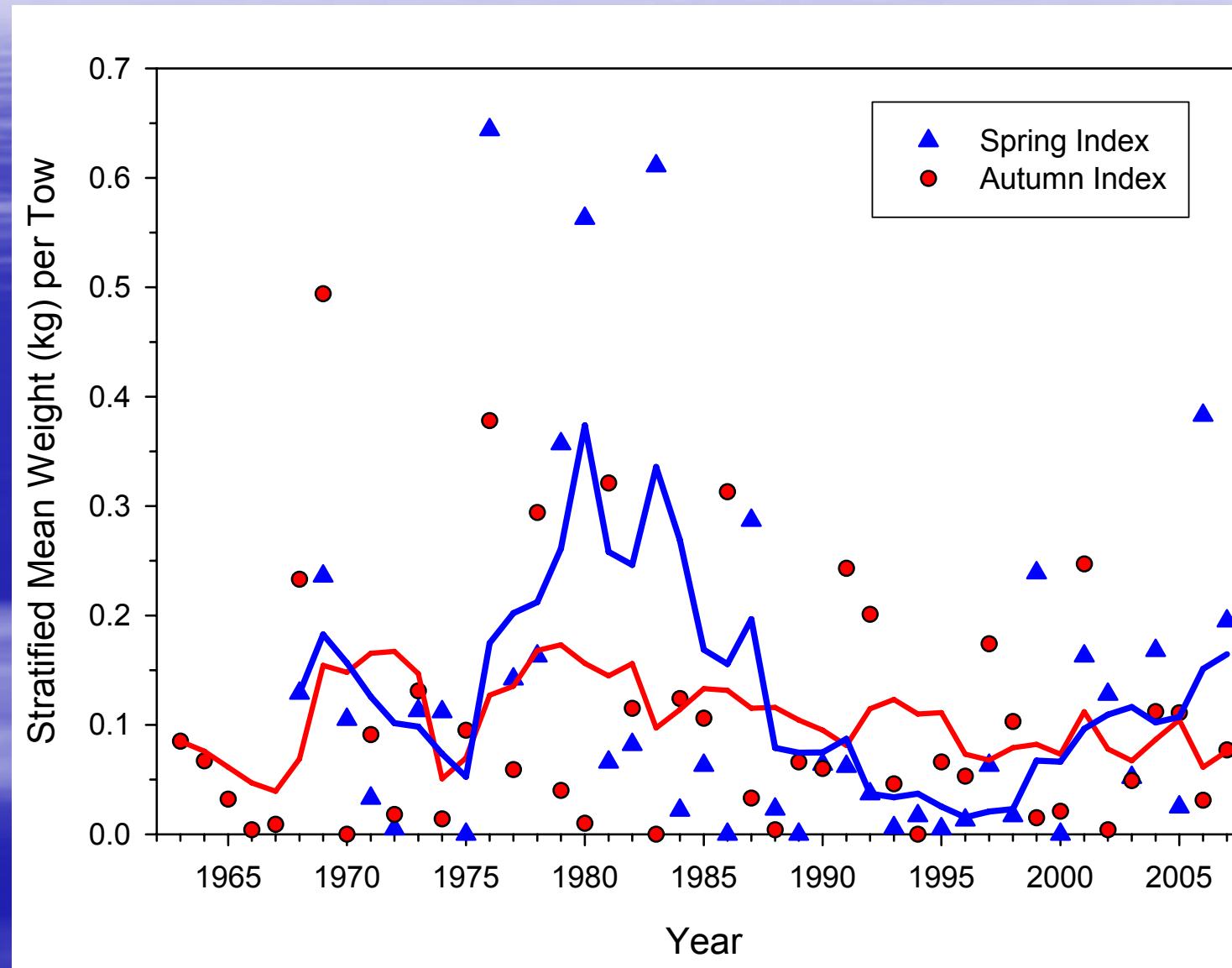
# Atlantic Halibut Commercial Catch



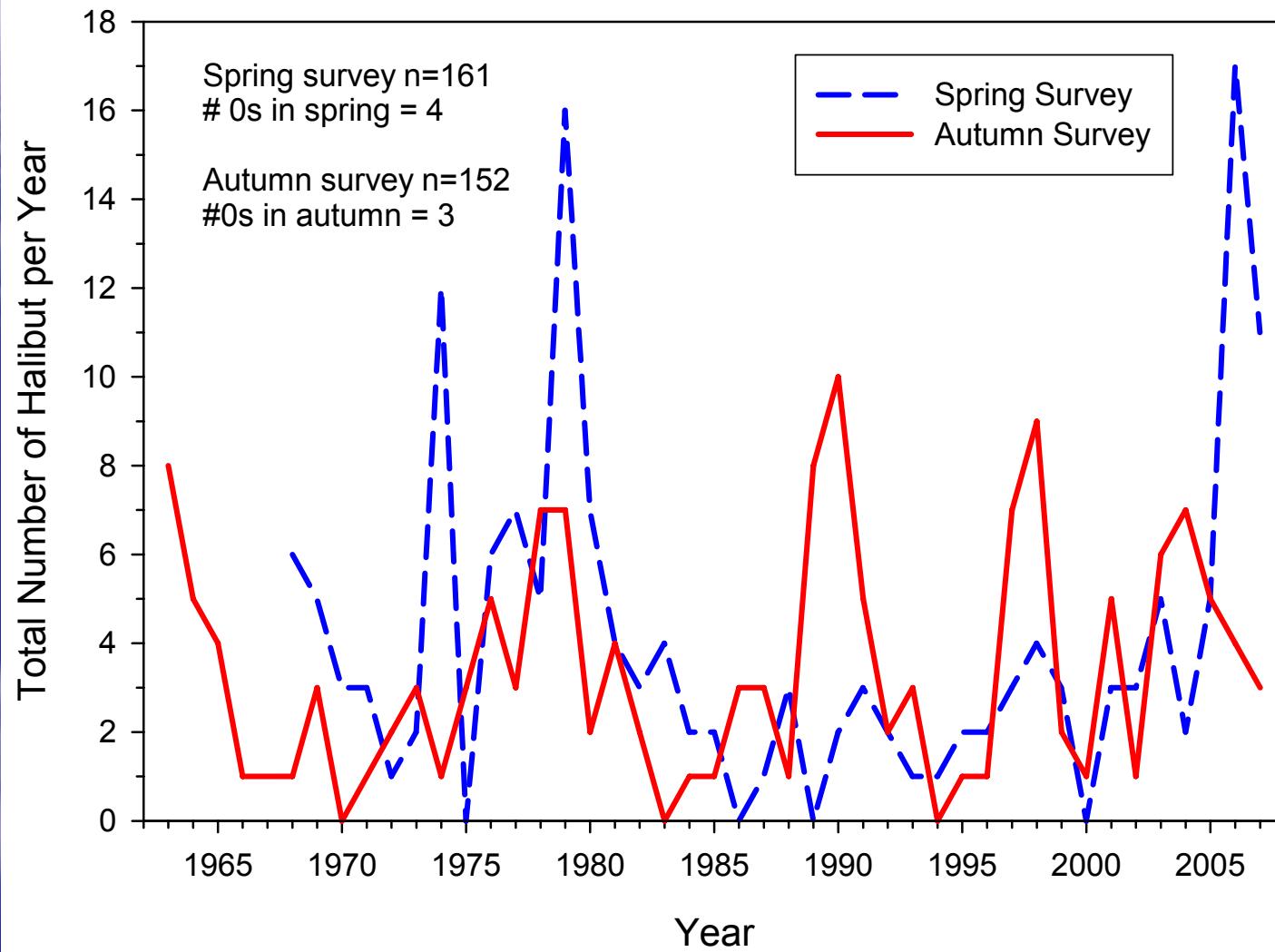


NEFSC survey strata used to define the Gulf of Maine/Georges Bank region of the Atlantic halibut stock.

# Atlantic Halibut Biomass Trends in NEFSC Surveys



## Total numbers of Atlantic halibut caught in NEFSC spring and autumn surveys per year



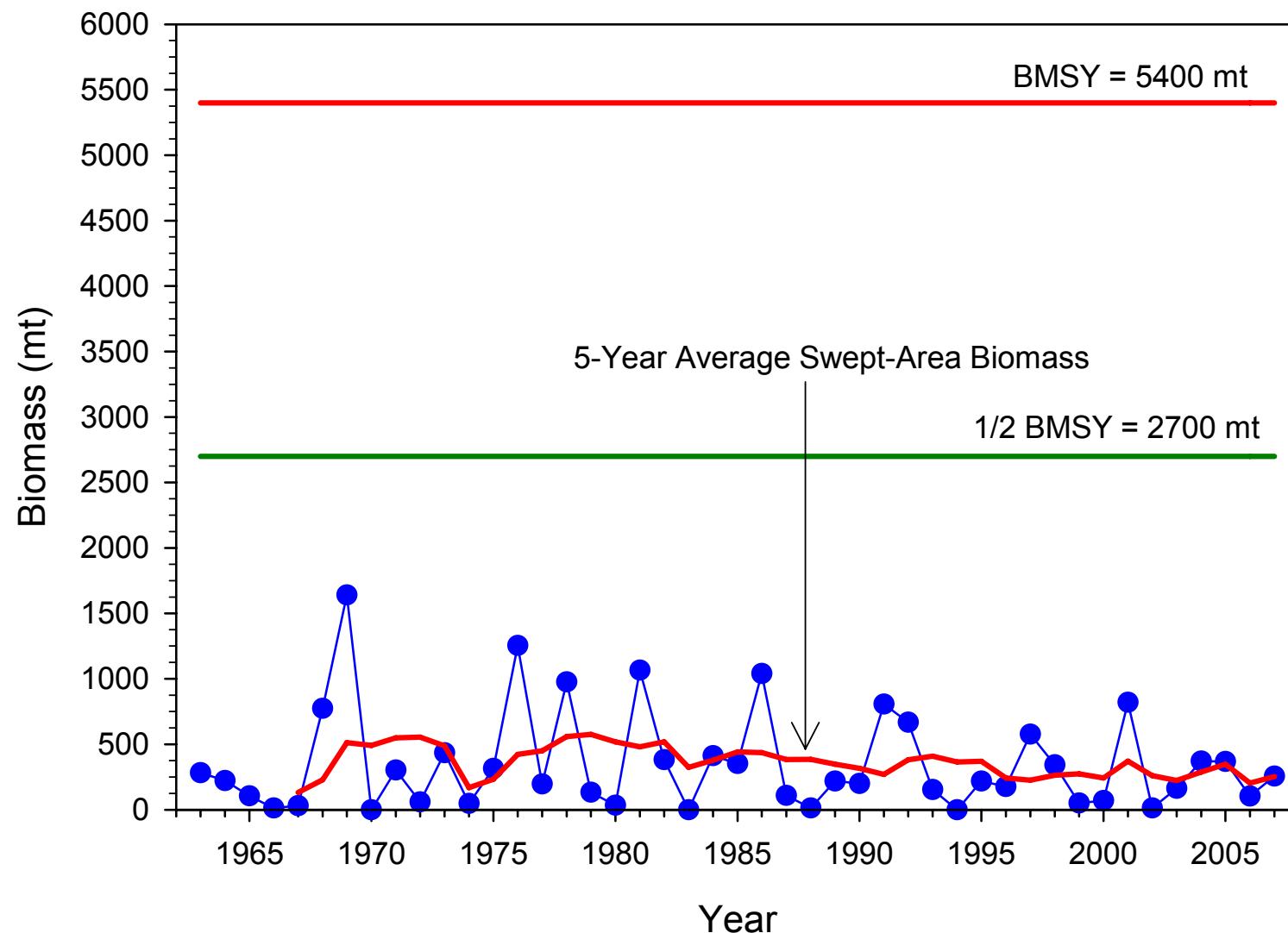
- No age data available
- No door, vessel or gear conversions available

# Index-Based Reference Point Determination

## Previous Reference Points

- Chose 300 mt as MSY proxy
  - 1893-1942 average landings of 480 mt not sustainable
- YPR and BPR analyses used to determine reference points
  - Used length-weight equations from McCracken (1958)
  - von Bertalanffy growth curves (Nielson and Bowering 1989)
- $F_{0.1} = 0.06$  for  $F_{MSY}$
- 60% of  $F_{0.1} = 0.04$  for  $F_{target}$
- $B_{MSY} = 5,400$  mt for  $B_{target}$
- $\frac{1}{2} B_{MSY} = 2,700$  mt for  $B_{threshold}$

Figure S2. Trends in swept-area biomass indices (mt) of Atlantic halibut from NEFSC autumn bottom trawl surveys.



# Index-Based Reference Point Determination

## Methods for Revised Reference Points

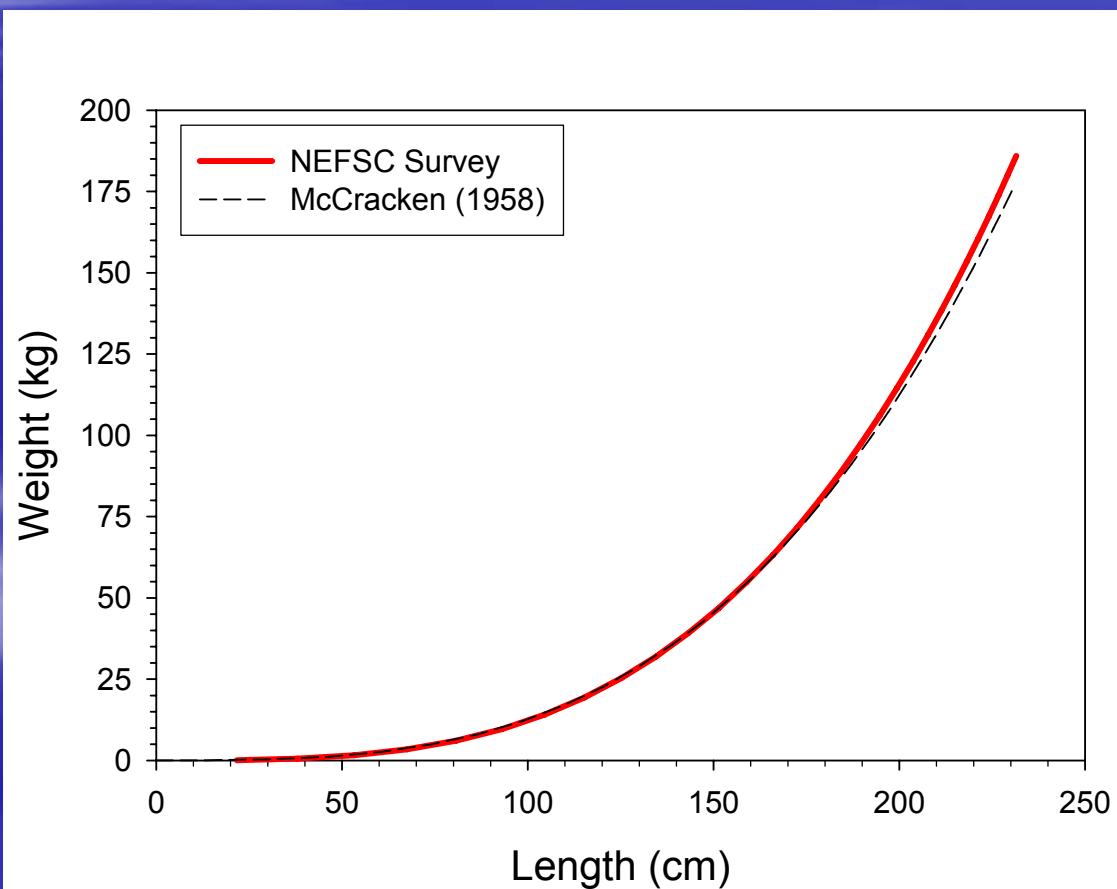
- Updated YPR and BPR analyses:
- NEFSC survey data to estimate length-weight parameters
- Sigourney (2002) aged halibut from NEFSC surveys and halibut experimental longline fishery
  - von Bertalanffy growth equation applied to length-weight equation to determine weight-at-age
- Percent maturity at age (Sigourney et al. 2006)

# Atlantic Halibut Female Length-Weight

Length (cm)	Weight (kg)
21.7	0.09
38.0	0.53
53.3	1.58
67.5	3.40
80.7	6.07
93.0	9.64
104.5	14.08
115.3	19.33
125.3	25.32
134.6	31.97
143.3	39.18
151.4	46.84
158.9	54.87
166.0	63.17
172.6	71.66
178.7	80.25
184.4	88.89
189.7	97.50
194.7	106.03
199.3	114.44
203.7	122.68
207.7	130.73
211.4	138.56
214.9	146.14
218.2	153.47
221.2	160.53
224.1	167.31
226.7	173.81
229.2	180.02
231.5	185.95

**1992-2005**  
GOM Mean Spring/Fall  
 $A = 0.003917567$   
 $B = 3.246485$   
 $W = AL^B$

McCracken (1958)  
 $W = 0.0000117*L^{3.15}$



# Atlantic Halibut Female Length at Age

Pooled Data Females  
Halibut Growth Rates

Mean Length			
Age	(cm)	LowerCI	UpperCI
0	-5.0	0.9	-18.7
1	13.1	11.4	11.4
2	30.0	21.4	38.8
3	45.8	30.9	63.7
4	60.5	40.0	86.3
5	74.2	48.6	106.9
6	87.0	56.7	125.7
7	98.9	64.5	142.7
8	110.0	71.9	158.2
9	120.3	78.9	172.3
10	130.0	85.5	185.1
11	139.0	91.9	196.7
12	147.4	97.9	207.3
13	155.2	103.6	217.0
14	162.5	109.0	225.7
15	169.3	114.2	233.7
16	175.7	119.1	240.9
17	181.6	123.7	247.5
18	187.1	128.2	253.5
19	192.3	132.4	258.9
20	197.1	136.4	263.9
21	201.5	140.2	268.4
22	205.7	143.8	272.5
23	209.6	147.2	276.2
24	213.2	150.5	279.6
25	216.6	153.6	282.7

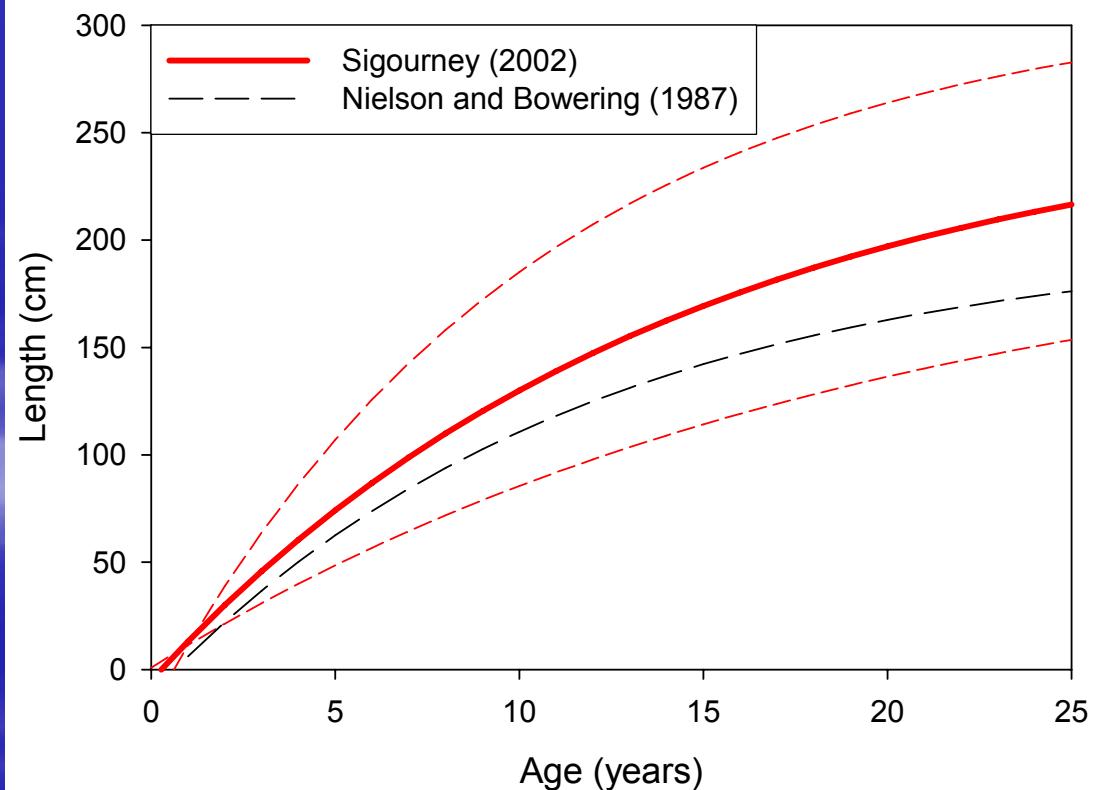
von Bertalanffy

$$L(t) = L_{\text{inf}}(1 - \exp(-K(t-t_0)))$$

	$L_{\text{inf}}$	$t_0$	K	$r^2$
Mean	263.2	0.27	0.07	0.878
LCI	212.8	-0.08	0.051	
UCI	313.6	0.61	0.095	

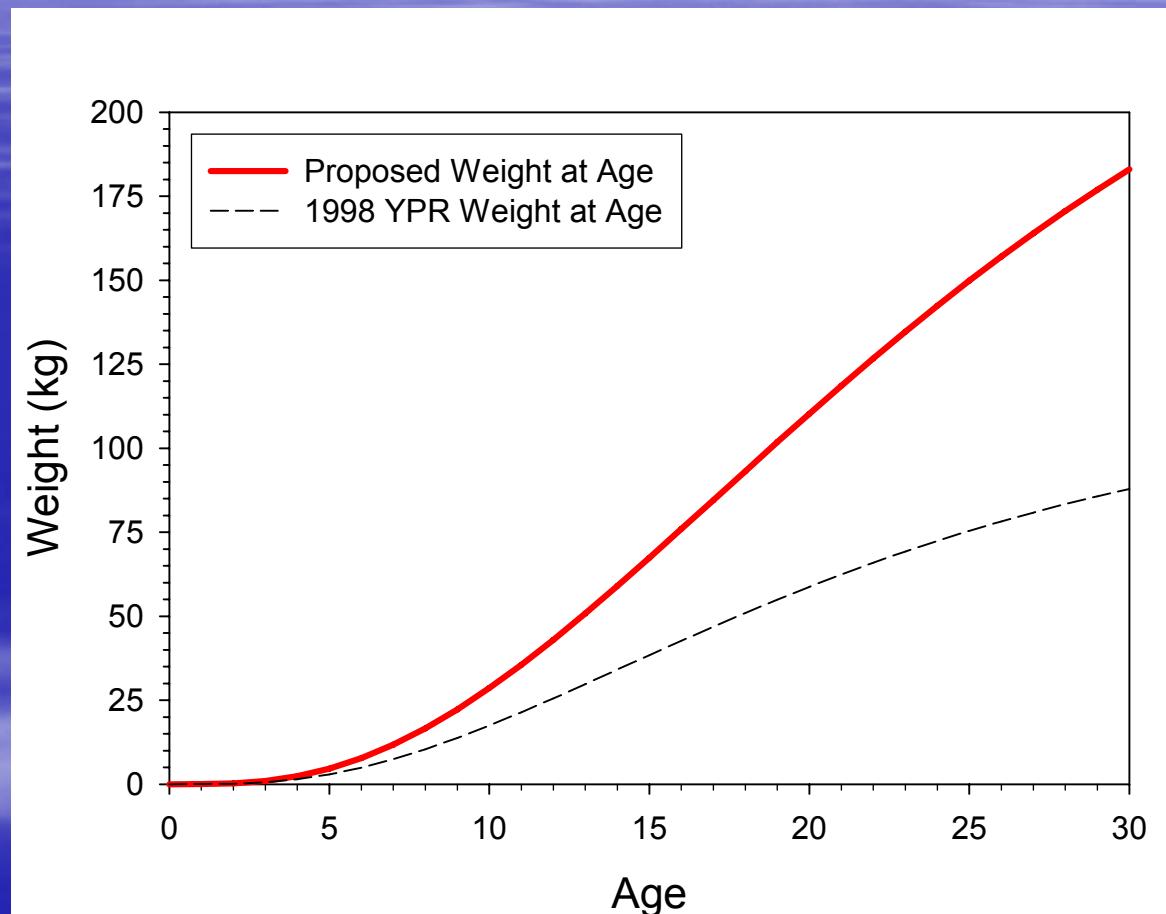
Nielson and Bowering (1989)

$$L(t) = 201.5(1 - e^{-0.0852026(t-0.640041)})$$



# Atlantic Halibut Female Weight at Age

Age	Length (cm)	Weight (kg)
0	-5.0	0.000
1	13.1	0.017
2	30.0	0.245
3	45.8	0.965
4	60.5	2.383
5	74.2	4.624
6	87.0	7.746
7	98.9	11.752
8	110.0	16.605
9	120.3	22.239
10	130.0	28.573
11	139.0	35.513
12	147.4	42.960
13	155.2	50.819
14	162.5	58.994
15	169.3	67.397
16	175.7	75.947
17	181.6	84.569
18	187.1	93.197
19	192.3	101.774
20	197.1	110.250
21	201.5	118.581
22	205.7	126.732
23	209.6	134.674
24	213.2	142.383
25	216.6	149.841
26	219.7	157.035
27	222.7	163.955
28	225.4	170.594
29	228.0	176.949
30	230.4	183.021



# Atlantic Halibut Female Maturity Curve

Age	Proportion Mature
0	0.02
1	0.04
2	0.06
3	0.10
4	0.15
5	0.23
6	0.34
7	0.46
8	0.59
9	0.71
10	0.80
11	0.87
12	0.92
13	0.95
14	0.97
15	0.98
16	0.99
17	0.99
18	1.00
19	1.00
20	1.00
21	1.00
22	1.00
23	1.00
24	1.00
25	1.00
26	1.00
27	1.00
28	1.00
29	1.00
30	1.00

Females

$$S(a) = 1/(1+\exp(-\alpha-\beta*a))$$

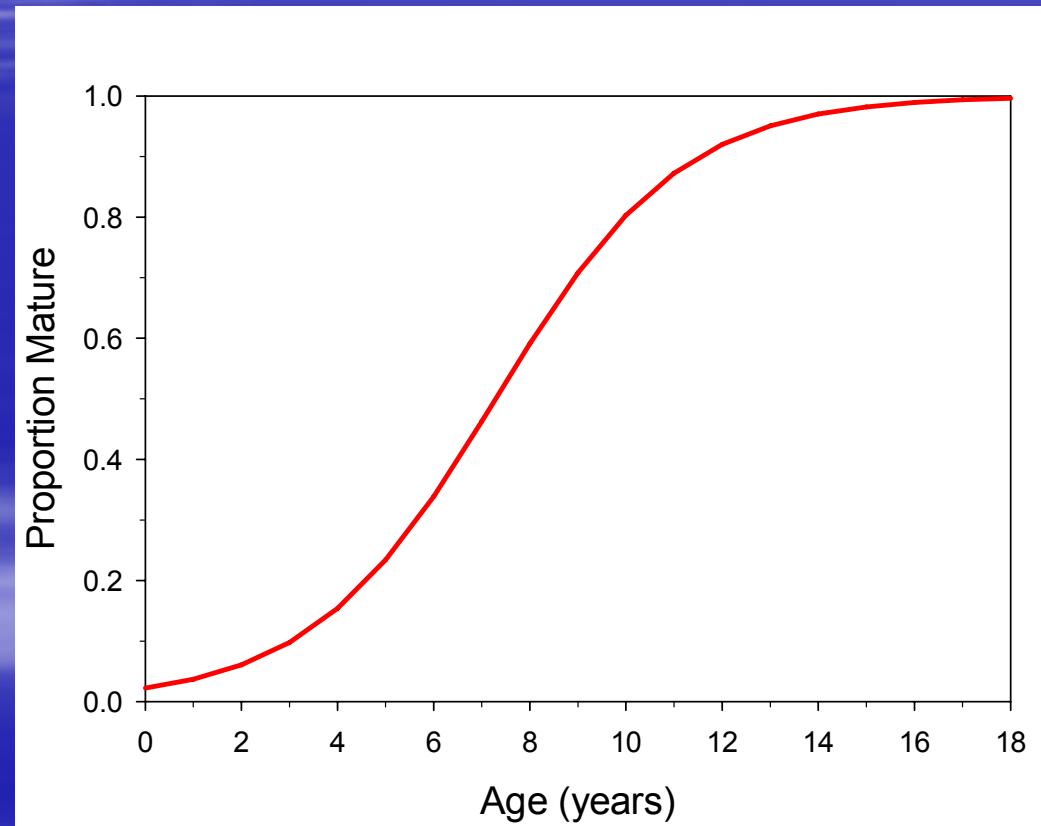
$$SR = A75-A25 = (2 \ln 3)/\beta$$

$$A75-A25 = 4.24$$

$$\beta = (2 \ln 3)/SR = 0.518$$

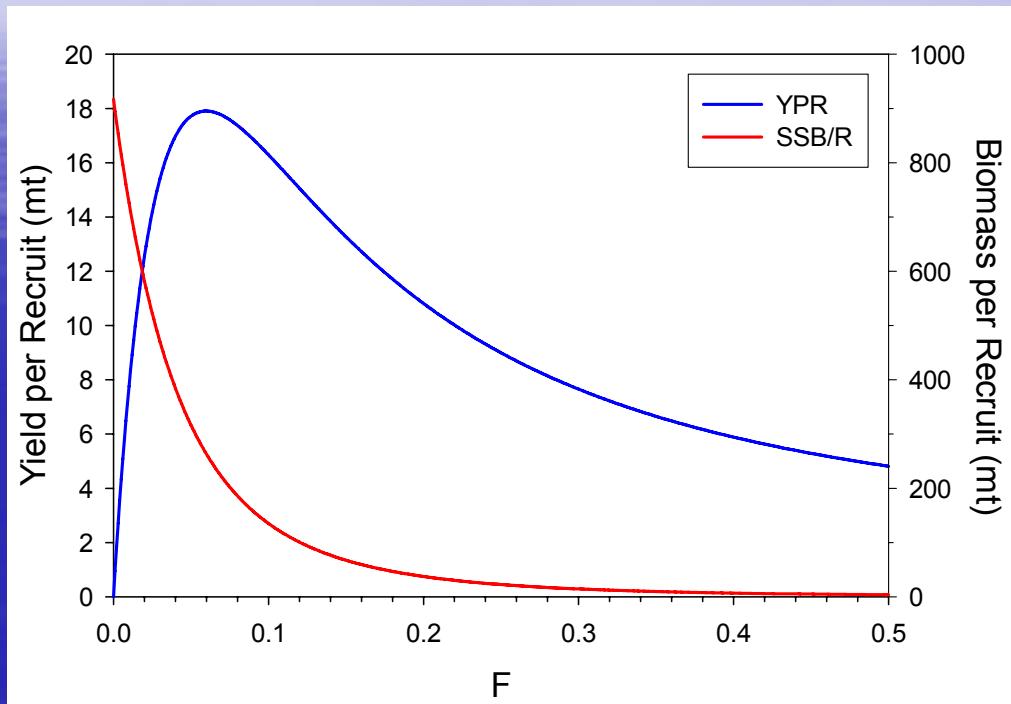
$$L50 = -\alpha/\beta$$

$$\alpha = -\beta * L50 = -3.778$$



# Atlantic Halibut YPR Analysis

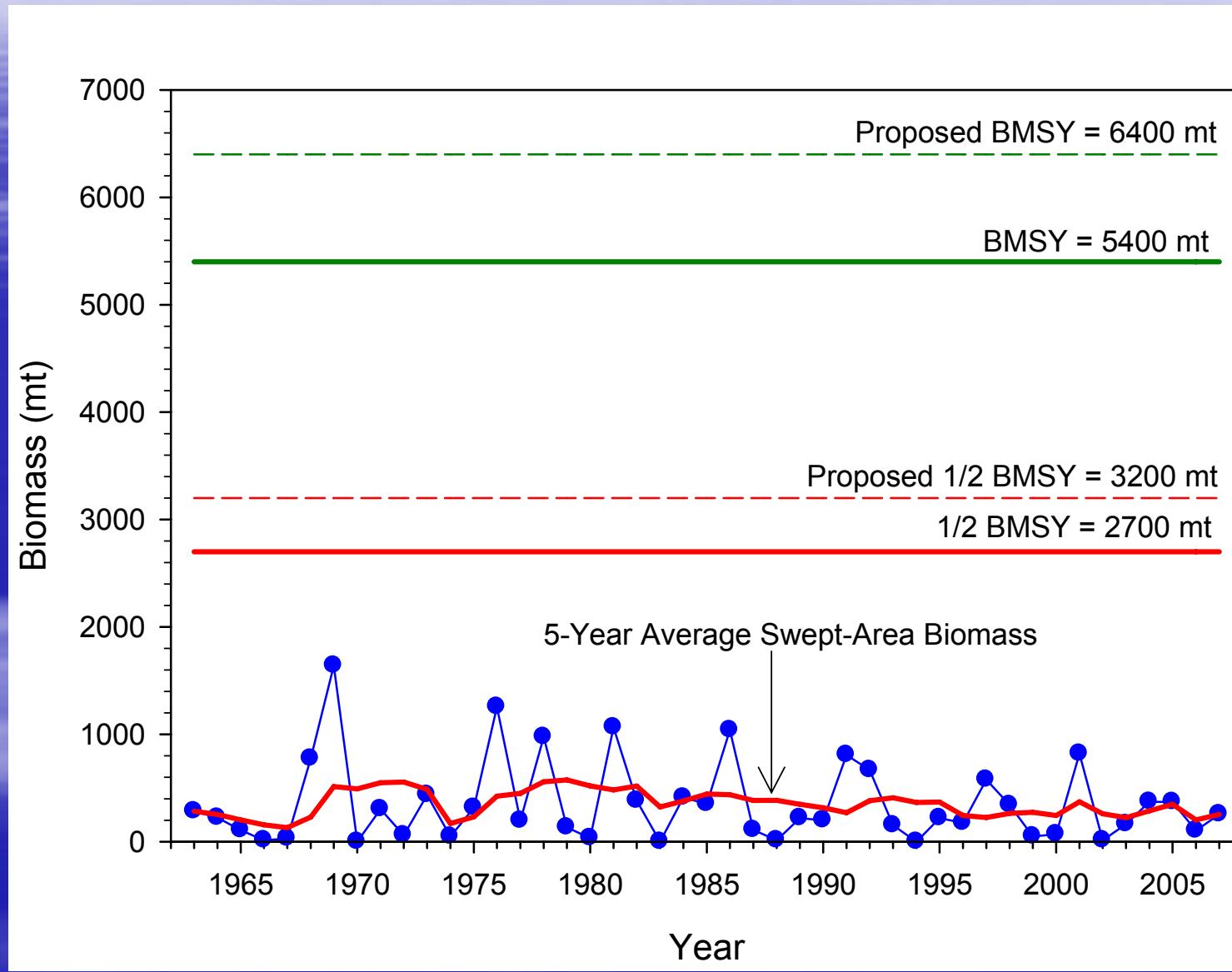
Age	Selectivity on Fishing Mortality	Natural Mortality Rate	Fraction Mature	Mean Weight (kg)
0	0	0.06	0.01	0.00
1	0	0.06	0.04	0.02
2	0	0.06	0.06	0.25
3	0	0.06	0.10	0.96
4	1	0.06	0.15	2.38
5	1	0.06	0.23	4.62
6	1	0.06	0.34	7.75
7	1	0.06	0.46	11.75
8	1	0.06	0.59	16.60
9	1	0.06	0.71	22.24
10	1	0.06	0.80	28.57
11	1	0.06	0.87	35.51
12	1	0.06	0.92	42.96
13	1	0.06	0.95	50.82
14	1	0.06	0.97	58.99
15	1	0.06	0.98	67.40
16	1	0.06	0.99	75.95
17	1	0.06	0.99	84.57
18	1	0.06	1.00	93.20
19	1	0.06	1.00	101.77
20	1	0.06	1.00	110.25
21	1	0.06	1.00	118.58
22	1	0.06	1.00	126.73
23	1	0.06	1.00	134.67
24	1	0.06	1.00	142.38
25	1	0.06	1.00	149.84
26	1	0.06	1.00	157.04
27	1	0.06	1.00	163.95
28	1	0.06	1.00	170.59
29	1	0.06	1.00	176.95
30-50	1	0.06	1.00	183.02



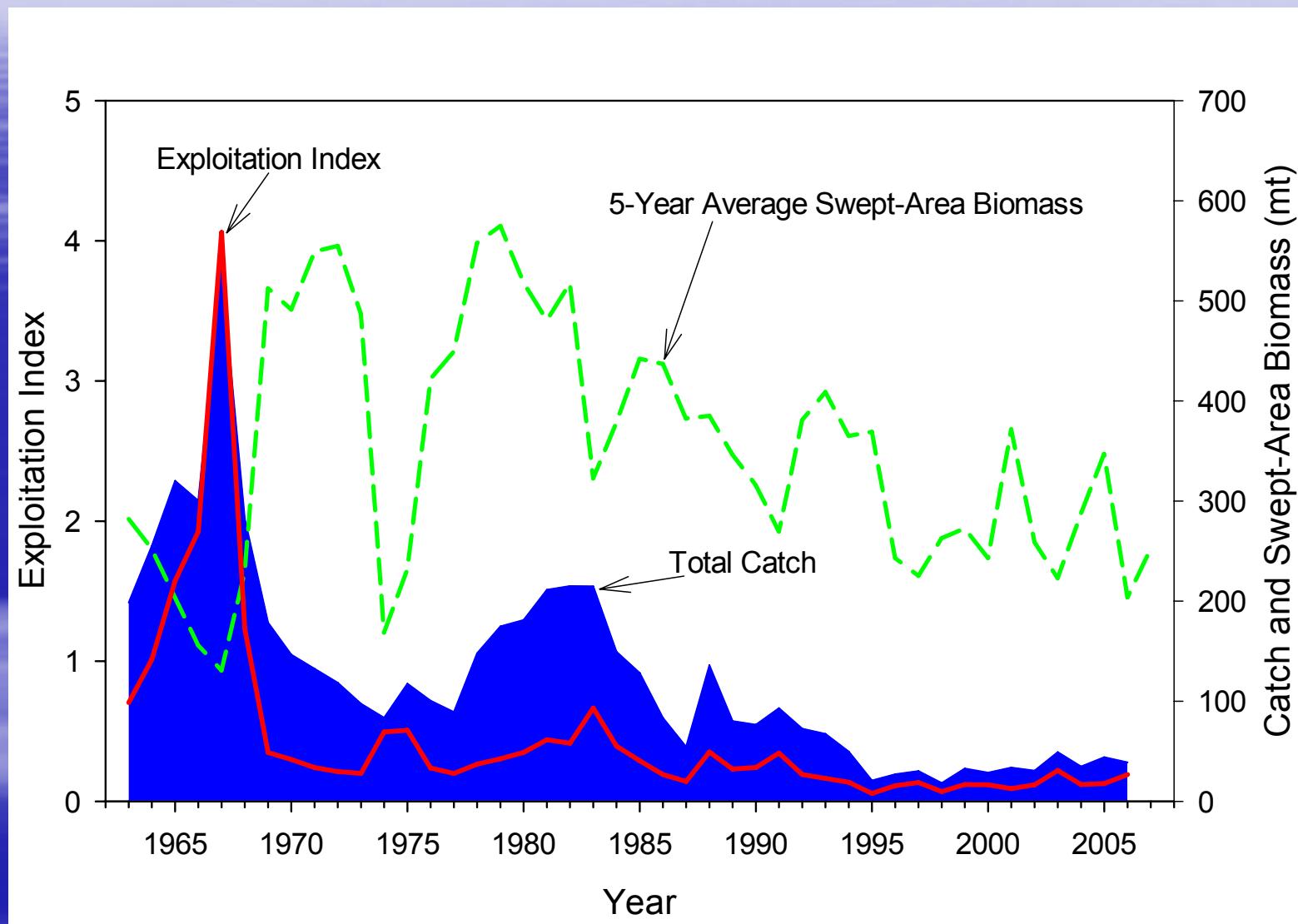
## Revised Reference Points

- $F_{0.1} = 0.04$  for  $F_{MSY}$
- 60% of  $F_{0.1} = 0.024$  for  $F_{target}$
- $B_{MSY} = 6,400$  mt for  $B_{target}$
- $\frac{1}{2} B_{MSY} = 3,200$  mt for  $B_{threshold}$

# Index-Based Reference Points



# Atlantic Halibut Exploitation Index



# Replacement Yield Model

## Methods for Replacement Yield Model

- Assumed a linear increase in catches from 1800-1893

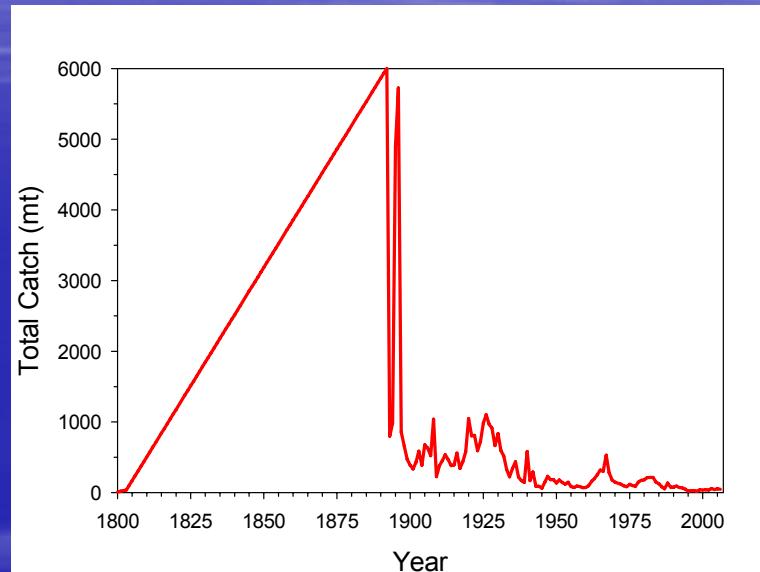
- Biomass is estimated as:

$$B_y = B_{y-1} + R_{y-1} - C_{y-1}$$

- Replacement yield is estimated as:

$$R_y = rB_y (1 - B_y / K)$$

- Annual growth of the population as a function of how far biomass is from the carrying capacity
- Biomass in the first year was set to K



# Replacement Yield Model

## Likelihood Function

- Model was fitted to the 5-year moving average of the NEFSC survey swept-area biomass index
- Likelihood function:
  - $-\ln L = \log(\delta) + 0.5 \sum (\ln(I_y) - \ln(B_y q))^2 / \delta^2 + p_1 + p_2$

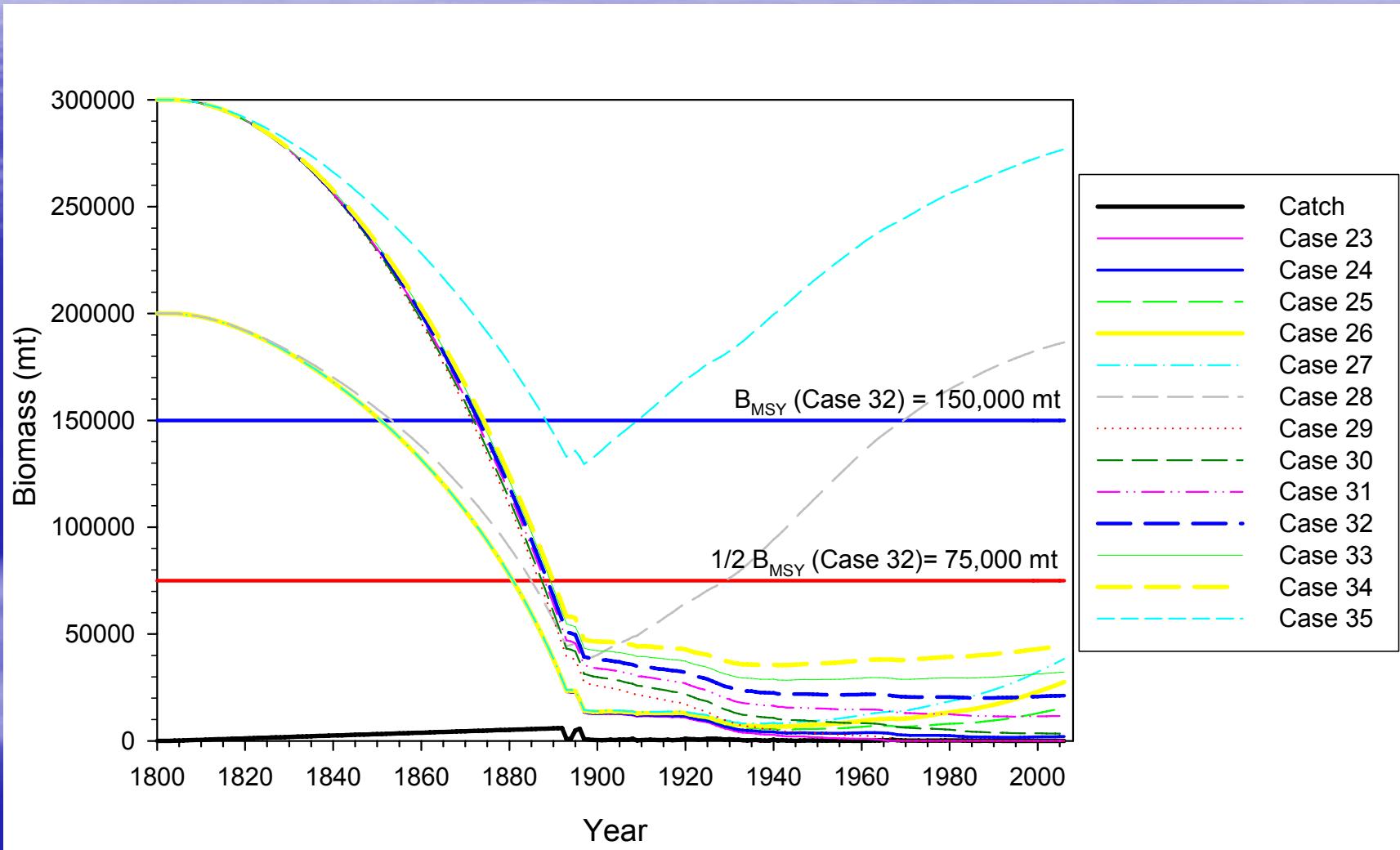
Includes:

- Survey residuals
- Constant standard deviation ( $\delta = 0.6$ )
- Penalty for biomass going to the minimum boundary in a given year
- Penalty for the difference between the model-estimated  $q$  and the assumption that the NEFSC autumn survey  $q$  is roughly 0.5

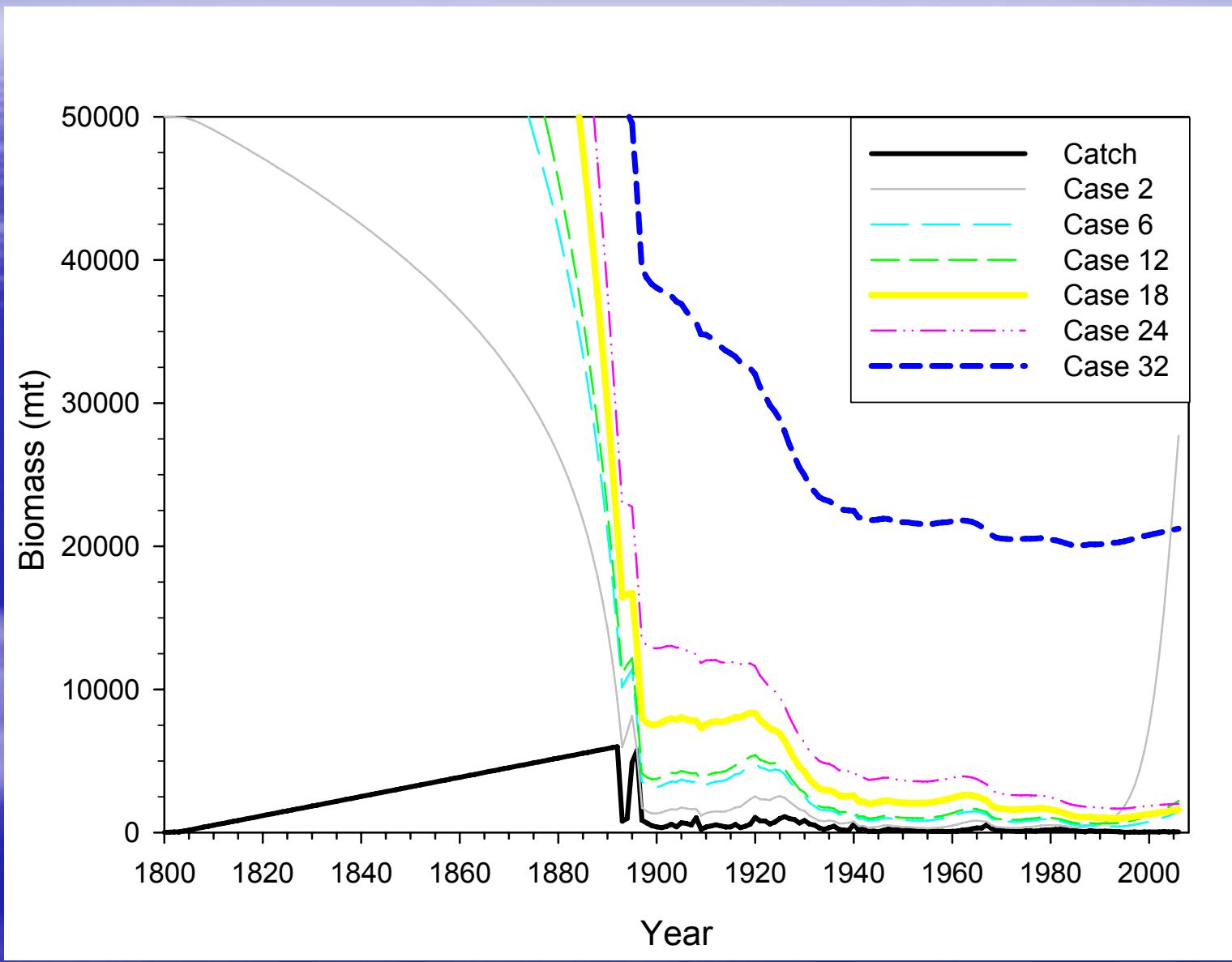
# Replacement Yield Model Simulations

	Case 1	Case 2	Case 3				
K	50000	50000	50000				
r	0.353807079975544	0.353807079975545	0.353807079975546				
-ln L	19201.398	141.895	198.056				
	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	
K	90000	90000	90000	90000	90000	90000	
r	0.16307849140	0.16307849145	0.16307849150	0.16307849155	0.16307849160	0.16307860000	
-ln L	805.999	23.482	22.557	25.079	28.249	65.574	
	Case 10	Case 11	Case 12	Case 13	Case 14	Case 15	Case 16
K	100000	100000	100000	100000	100000	100000	100000
r	0.139766823	0.139766824	0.139766825	0.139766826	0.139766827	0.139766828	0.13977
-ln L	2888.269	34.087	22.373	29.172	35.703	41.399	16.912
	Case 17	Case 18	Case 19	Case 20	Case 21	Case 22	
K	150000	150000	150000	150000	150000	150000	
r	0.0708170	0.0708175	0.0708180	0.0708185	0.0708190	0.0720000	
-ln L	862.258	15.744	15.858	18.157	20.515	8.797	
	Case 23	Case 24	Case 25	Case 26	Case 27	Case 28	
K	200000	200000	200000	200000	200000	200000	
r	0.0368	0.0369	0.037	0.0371	0.0372	0.045	
-ln L	168917325.973	13.800	15.152	16.674	17.078	8.782	
	Case 29	Case 30	Case 31	Case 32	Case 33	Case 34	Case 35
K	300000	300000	300000	300000	300000	300000	300000
r	0.003	0.004	0.005	0.006	0.007	0.008	0.030
-ln L	18555487.020	12.982	9.242	8.935	8.948	9.029	8.593

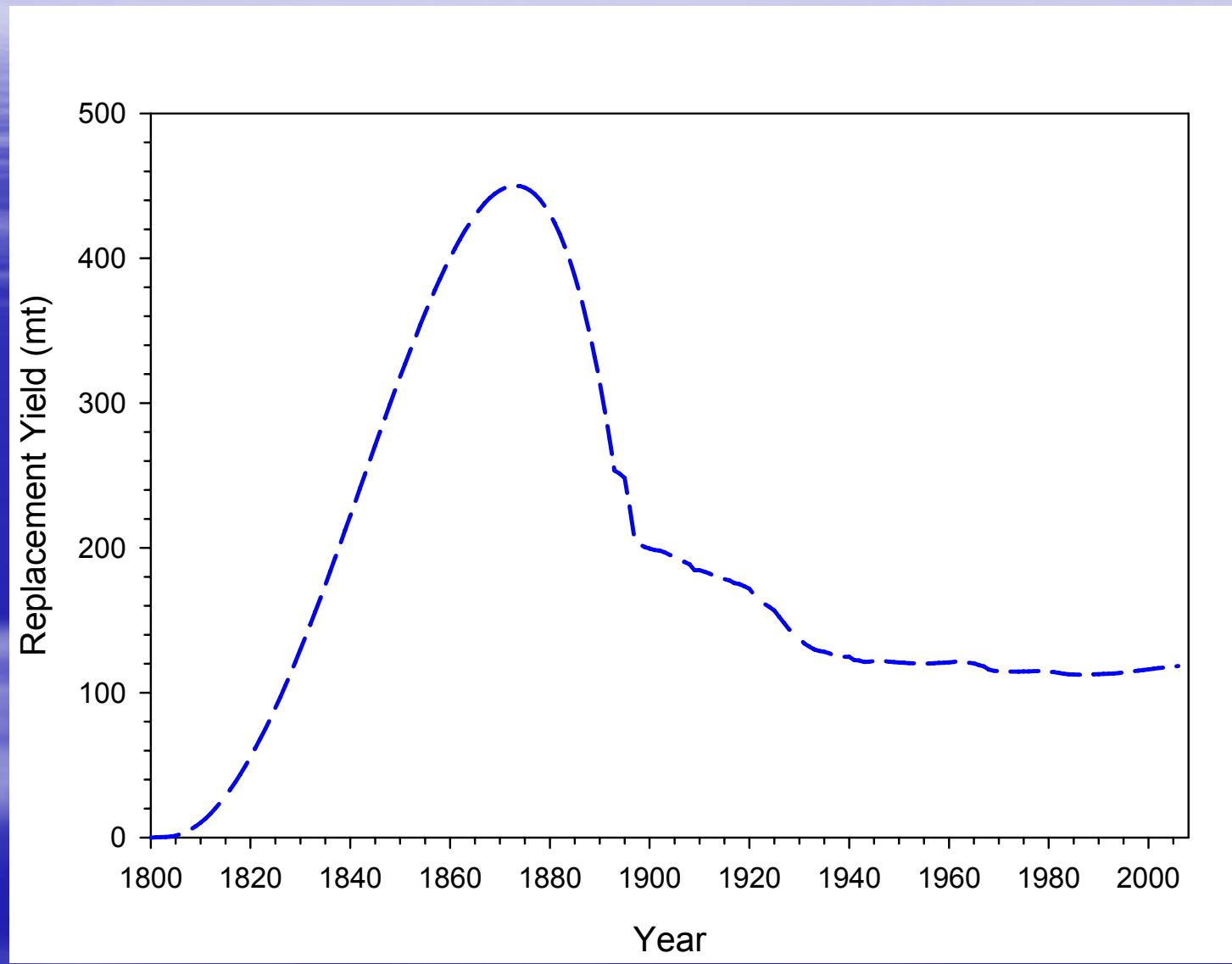
# Biomass from Replacement Yield Model Runs



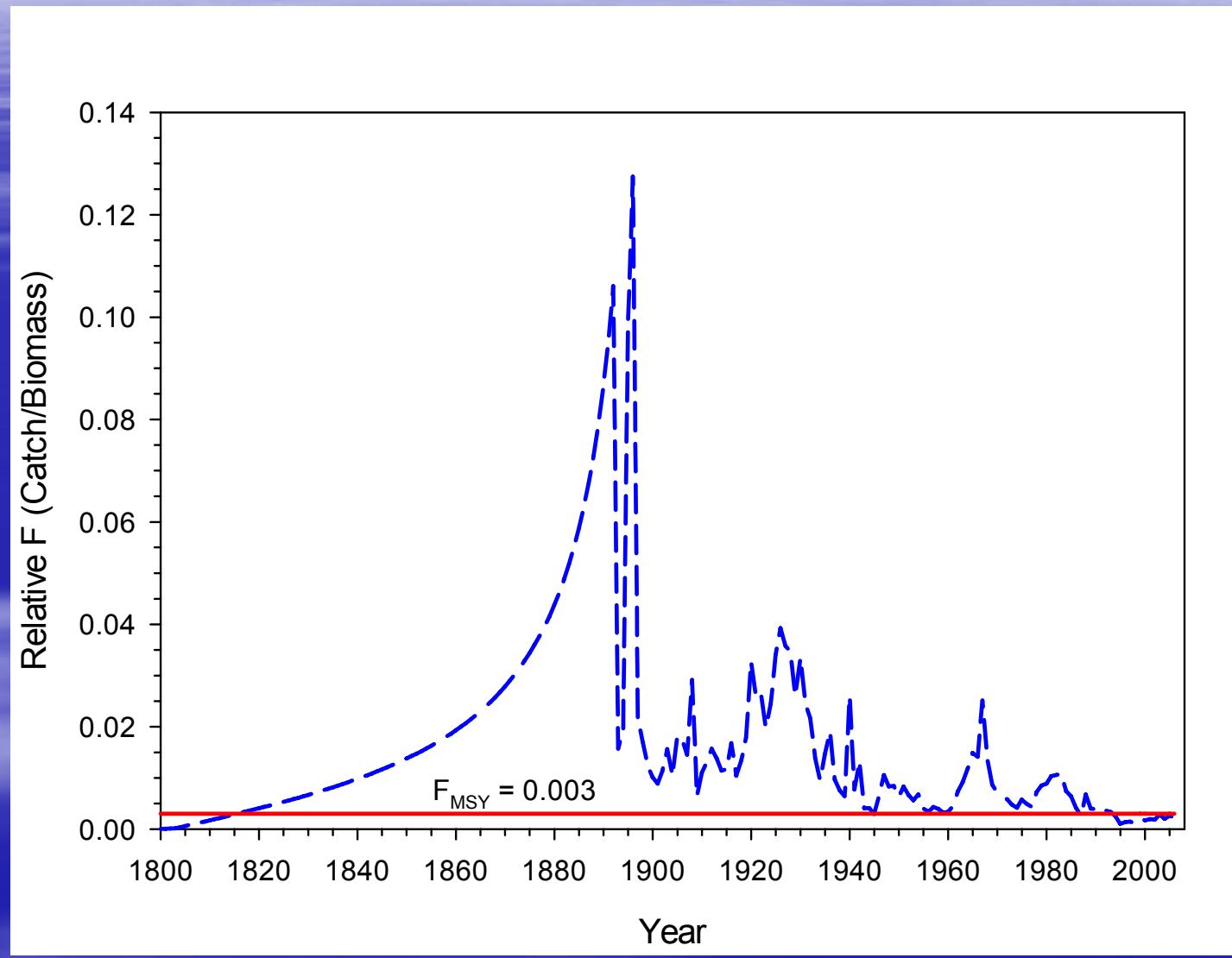
# Biomass from Replacement Yield Model Runs



# Replacement Yield from Case 32



## Relative F from Case 32



# Reference Point Determination

## Previous Index-Based Reference Points:

	Threshold	Target	Current Estimate	% Threshold
Fishing mortality	0.06	0.04	none	n/a
Stock biomass	2,700 mt	5,400 mt	252 mt	9%

## Revised Index-Based Reference Points:

	Threshold	Target	Current Estimate	% Threshold
Fishing mortality	0.04	0.02	none	n/a
Stock biomass	3,200 mt	6,400 mt	252 mt	8%

## Replacement Yield Model Reference Points:

	Threshold	Target	Current Estimate	% Threshold
Fishing mortality	0.003	n/a	0.0022	75%
Stock biomass	75,000 mt	150,000 mt	21,200 mt	28%

# Atlantic Halibut Model Comparison

## Index-Based Assessment Strengths

- Previously accepted method
- Often used in data poor situations
- Updated reference points

## Index-Based Assessment Weaknesses

- Started 100 years after fishery collapsed
- Below detectability levels?
- Little contrast/trend/tracking
- No conversion factors (door, net, or vessel)
- No F, overfishing status
- No conversion factors for *FRV Henry Bigelow*
  - Current index end after 2008

# Atlantic Halibut Model Comparison

## Replacement Yield Model Strengths

- Appropriate for data poor stocks
- Uses entire time series of catch
  - Direction/relative magnitude of changes
- Fit to fishery-independent survey
- Estimate current F, overfishing status

## Replacement Yield Model Weaknesses

- Relies on fishery-dependent data
- Sensitive to K and r inputs
- Tendency for  $-\ln L$  to decrease with increasing K

# Atlantic Halibut Minimum Size Limit

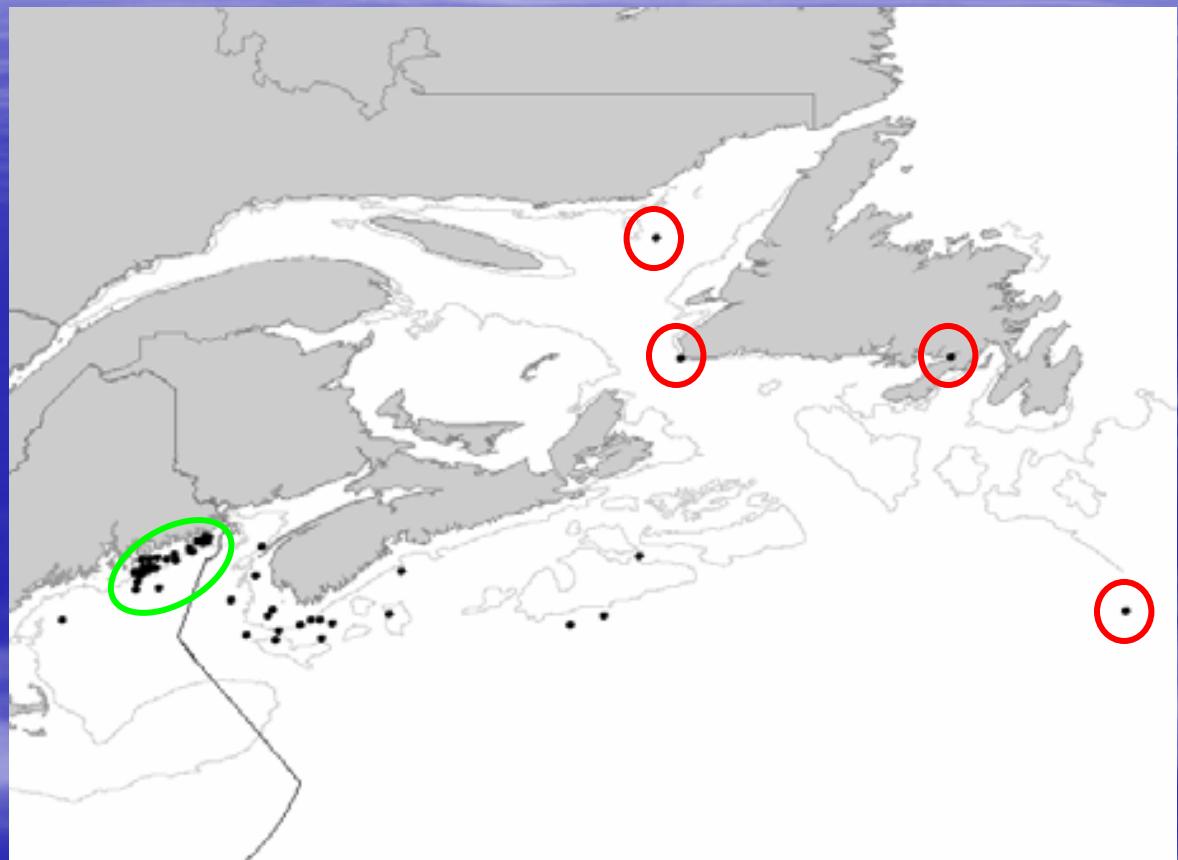
- Sigourney (2006) estimated female  $L_{50} \sim 103$  cm

Discarded halibut					Kept halibut				
Year	Mean Length		Min. Length		Year	Mean Length		Min. Length	
	(cm)	Std Err	N	(cm)		(cm)	Std Err	N	(cm)
1992	33.0	.	1	33	1990	46.6	2.0012	6	42
1993	31.3	13.3458	3	17	1991	92.0	.	1	92
1994	42.4	5.1049	5	24	1992	67.1	5.2457	11	29
1995	27.2	5.4858	6	18	1993	62.8	5.5333	10	42
1997	36.3	2.1858	3	32	1994	73.3	5.0781	16	46
1999	62.0	.	1	62	1995	79.6	4.6356	29	42
2000	57.0	4.0778	13	18	1996	69.2	10.027	5	50
2001	67.5	2.9518	13	48	1997	67.5	11.3893	6	44
2002	70.2	4.7648	13	38	2001	118.0	6	2	112
2003	64.0	1.6363	91	31	2002	88.0	9.0738	6	52
2004	57.1	1.3502	87	26	2003	81.0	5.349	29	41
2005	60.4	1.3042	160	33	2004	83.9	3.9709	33	43
2006	63.0	1.495	107	38	2005	76.4	2.5691	80	40
2007	64.3	1.9969	75	24	2006	84.9	3.5611	37	50
					2007	90.5	4.225	33	49

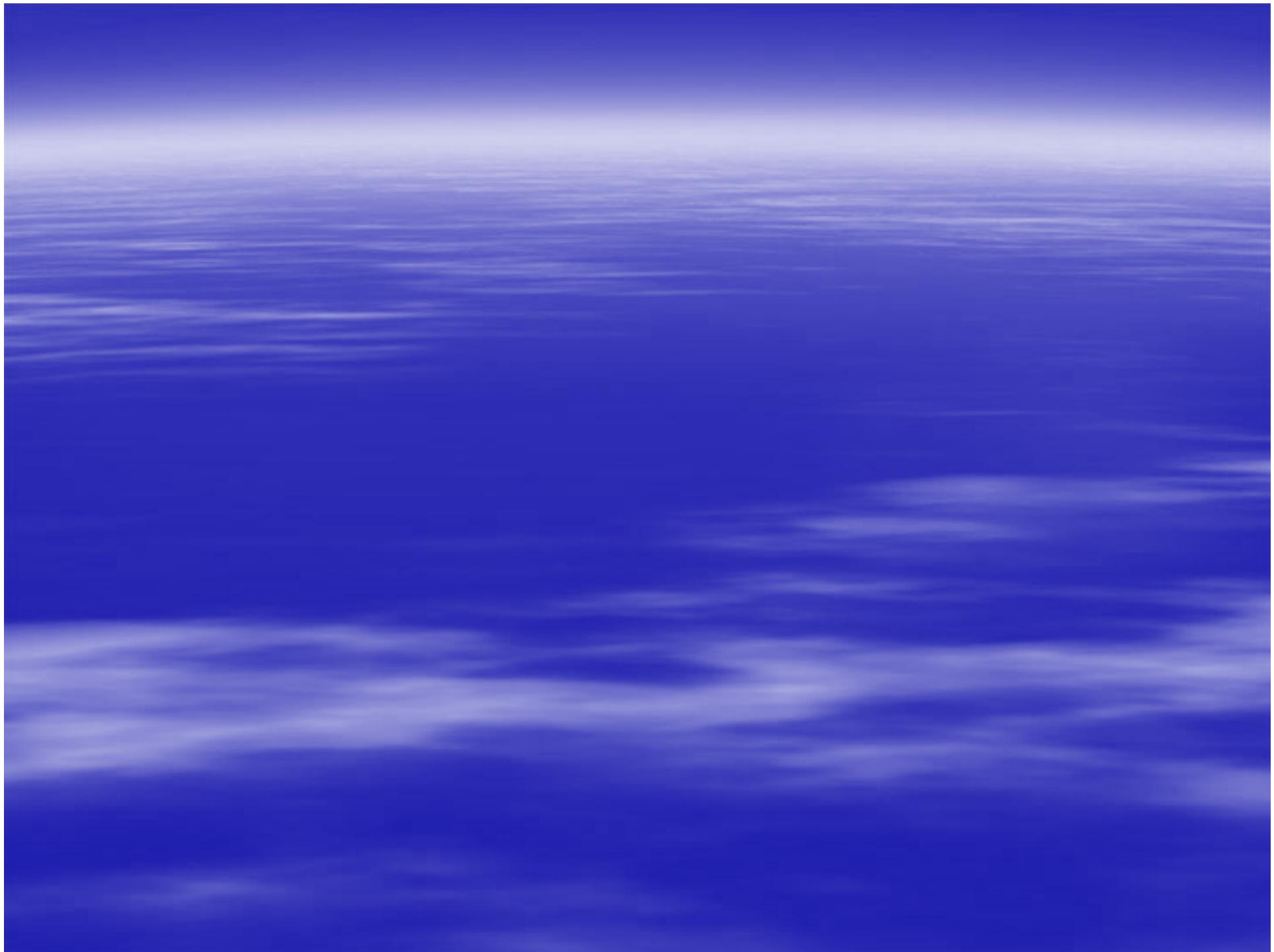
Note: 1999-2007 average observed minimum size for kept halibut = 55cm  
Minimum size regulation from 1999 to present = 91cm

# 2000-2004 Experimental Halibut Fishery

- Kanwit (2007)
- 1,611 retained halibut
- 825 tagged and released
- 92 recaptured
- **28%** of recaptures in Canadian waters
- Mean distance traveled = 151 km (1,758 km max)
- Transboundary movement
- Stock area should be reconsidered



- Release area in green
- Black dots represent recapture locations



# Index-Based Reference Point Determination

## Methods for Revised Reference Points

- Updated YPR and BPR analyses
- Performed bootstrap analyses of NEFSC spring and autumn data
  - Estimated parameters for length-weight equation:  
 $W = \alpha L^\beta$
- Sigourney (2002) aged halibut from NEFSC surveys and halibut experimental longline fishery
  - Von Bertalanffy age-length key (females only) applied to length-weight equation to get weight-at-age for YPR
- Percent maturity at age (Sigourney et al. 2006) used to calculate maturity ogive:
  - $S(a) = (1 + e^{(-\alpha - \beta a)})^{-1}$   
Where: a is age  
 $\beta$  is assumed to be equal to  $(2 \ln 3) / (L_{75} - L_{25})$ , estimated to be 0.518  
 $\alpha$  is assumed to be equal to  $-\beta L_{50}$ , estimated to be -3.778

# Index-Based Reference Point Determination

## Methods for Revised Reference Points (cont.)

- Weight at age and maturity at age used plus group at age 30
  - maximum age 50 years
- $-\ln(0.05)/\text{max age used}$  as proxy for  $M \sim 0.06$
- assumed knife edge selectivity at age 4
- Assumed MSY = 300 mt

## Revised Reference Points

- $F_{0.1} = 0.04$  as proxy for FMSY
- 60% of  $F_{0.1} = 0.024$  for  $F_{\text{target}}$
- $B_{\text{target}} = 6,400$  mt as proxy for BMSY
- $\frac{1}{2}$  BMSY proxy = 3,200 mt for  $B_{\text{threshold}}$

# Atlantic Halibut Discards from Observer Database

YEAR	COMNAME	NESPP4	DISP_DESC	LIVE_WT(lbs)	OBS_HAULS
1989	HALIBUT, ATLANTIC	1595	DISCARD	162	25
1990	HALIBUT, ATLANTIC	1595	DISCARD	244	22
1991	HALIBUT, ATLANTIC	1595	DISCARD	518	48
1992	HALIBUT, ATLANTIC	1595	DISCARD	144	17
1993	HALIBUT, ATLANTIC	1595	DISCARD	120	11
1994	HALIBUT, ATLANTIC	1595	DISCARD	44	8
1995	HALIBUT, ATLANTIC	1595	DISCARD	136.6	12
1996	HALIBUT, ATLANTIC	1595	DISCARD	22	4
1997	HALIBUT, ATLANTIC	1595	DISCARD	44	11
1998	HALIBUT, ATLANTIC	1595	DISCARD	6	1
1999	HALIBUT, ATLANTIC	1595	DISCARD	1027	4
2000	HALIBUT, ATLANTIC	1595	DISCARD	443	30
2001	HALIBUT, ATLANTIC	1595	DISCARD	430	22
2002	HALIBUT, ATLANTIC	1595	DISCARD	1577	44
2003	HALIBUT, ATLANTIC	1595	DISCARD	2604.8	123
2004	HALIBUT, ATLANTIC	1595	DISCARD	3722.6	182
2005	HALIBUT, ATLANTIC	1595	DISCARD	10084	533
2006	HALIBUT, ATLANTIC	1595	DISCARD	5037	243
2007	HALIBUT, ATLANTIC	1595	DISCARD	3952.8	192
2008	HALIBUT, ATLANTIC	1595	DISCARD	151.2	19

# Kept Atlantic Halibut from Observer Database

YEAR	COMNAME	NESPP4	DISP_DESC	LIVE_WT(lbs)	OBS_HAULS
1989	HALIBUT, ATLANTIC	1595	KEPT	692	16
1990	HALIBUT, ATLANTIC	1595	KEPT	694	42
1991	HALIBUT, ATLANTIC	1595	KEPT	2892	124
1992	HALIBUT, ATLANTIC	1595	KEPT	3360	110
1993	HALIBUT, ATLANTIC	1595	KEPT	1596	58
1994	HALIBUT, ATLANTIC	1595	KEPT	2375.5	67
1995	HALIBUT, ATLANTIC	1595	KEPT	2226	48
1996	HALIBUT, ATLANTIC	1595	KEPT	356	24
1997	HALIBUT, ATLANTIC	1595	KEPT	1059.4	44
1998	HALIBUT, ATLANTIC	1595	KEPT	32	3
1999	HALIBUT, ATLANTIC	1595	KEPT	196.5	7
2000	HALIBUT, ATLANTIC	1595	KEPT	362	10
2001	HALIBUT, ATLANTIC	1595	KEPT	473	6
2002	HALIBUT, ATLANTIC	1595	KEPT	1249.5	17
2003	HALIBUT, ATLANTIC	1595	KEPT	3834.4	63
2004	HALIBUT, ATLANTIC	1595	KEPT	4035	81
2005	HALIBUT, ATLANTIC	1595	KEPT	12320.1	237
2006	HALIBUT, ATLANTIC	1595	KEPT	8345.8	103
2007	HALIBUT, ATLANTIC	1595	KEPT	5749.9	116
2008	HALIBUT, ATLANTIC	1595	KEPT	149.85	9

# Discard Reasons for Atlantic Halibut

REASON	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
DISCARDED GENERAL, UNKNOWN DISCARD REASON	24	21	44	14	10	5	.	.	.	.	.	.	.	.	.	2	.	.	2
NO MARKET, BUT RETAINED FOR OBSERVER FOR SCIENTIFIC PURPOSES	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	.	1	
NO MARKET, QUOTA FILLED	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	
NO MARKET, REASON NOT SPECIFIED.	.	.	.	.	.	.	1	.	3	.	1	9	2	.	19	16	48	13	13
NO MARKET, TOO SMALL	.	.	.	.	.	1	2	2	6	1	.	2	.	1	9	15	10	1	1
NOT BROUGHT ON BOARD, FELL OUT/OFF OF GEAR	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
OTHER, DISCARDED	.	.	3	2	1	1	.	.	.	.	1	.	.	.	.	.	1	.	.
POOR QUALITY, HAGFISH DAMAGE	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
POOR QUALITY, REASON NOT SPECIFIED	.	1	1	1	.	.	.	.	.	.	.	.	.	.	2	.	1	.	.
POOR QUALITY, SANDFLEA DAMAGE	.	.	.	.	.	1	.	.	.	.	.	.	.	.	1	1	3	3	2
POOR QUALITY, SHARK DAMAGE	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	1	.	.
REGULATIONS PROHIBIT ANY RETENTION.	.	.	.	.	.	.	.	.	.	1	22	10	28	10	7	9	15	9	.
REGULATIONS PROHIBIT RETENTION, NO QUOTA IN AREA.	.	.	.	.	.	5	.	.	.	.	.	.	1	.	4	.	.	1	
REGULATIONS PROHIBIT RETENTION, QUOTA FILLED.	.	.	.	.	.	.	.	.	.	.	1	3	4	1	6	29	12	15	.
REGULATIONS PROHIBIT RETENTION, REASON NOT SPECIFIED.	.	.	.	.	.	.	.	2	.	.	5	2	1	3	6	9	4	.	.
REGULATIONS PROHIBIT RETENTION, TOO SMALL	.	.	.	.	.	.	4	2	.	1	1	6	8	75	123	419	193	148	
REGULATIONS PROHIBIT RETENTION, WITH EGGS.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	
RETAINING ONLY CERTAIN SIZE BETTER PRICE TRIP QUOTA IN EFFECT.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	1	1	1	.	
UPGRADED	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	2	.	

# Replacement Yield Model

## Methods for Replacement Yield Model

- Assumed a linear increase in catches from 1800-1893
- Replacement yield model where estimated biomass is defined as:

- $B_y = B_{y-1} + R_{y-1} - C_{y-1}$

Where:

$B_y$  is the biomass at the start of year  $y$

$B_{y-1}$  is the biomass at the start of the previous year

$C_{y-1}$  is the total catch in the previous year

$R_{y-1}$  is the replacement yield in the previous year

- Replacement yield is defined as:

- $R_y = rB_y (1 - B_y / K)$

Where:

$r$  is the intrinsic rate of growth

$K$  is the carrying capacity

- Biomass in the first year was set to  $K$

# Replacement Yield Model

## Likelihood Function

- Model was fitted to the 5-year moving average of the NEFSC swept-area biomass index
- Likelihood function:
  - $-\ln L = \log(\delta) + 0.5 \sum (\ln(I_y) - \ln(B_y q))^2 / \delta^2 + p_1 + p_2$

Where:

$\delta$  is a constant

$I_y$  is the swept-area biomass index in year  $y$

$q$  is the catchability of the NEFSC fall survey: exponent of the average of  $\ln(I_y) - \ln(B_y)$

$p_1$  is the sum of the penalties for biomass going to the defined minimum boundary in a given year

$p_2$  is a penalty for the difference between the model-estimated  $q$  and the assumption that the NEFSC autumn survey  $q$  is roughly 0.5

# Reference Point Determination

## Previous Index-Based Reference Points:

	Threshold	Target	Current Estimate	% Threshold
Fishing mortality	0.06	0.04	none	n/a
Stock biomass	2,700 mt	5,400 mt	252 mt	9%

## Revised Index-Based Reference Points:

	Threshold	Target	Current Estimate	% Threshold
Fishing mortality	0.04	0.02	none	n/a
Stock biomass	3,200 mt	6,400 mt	252 mt	8%

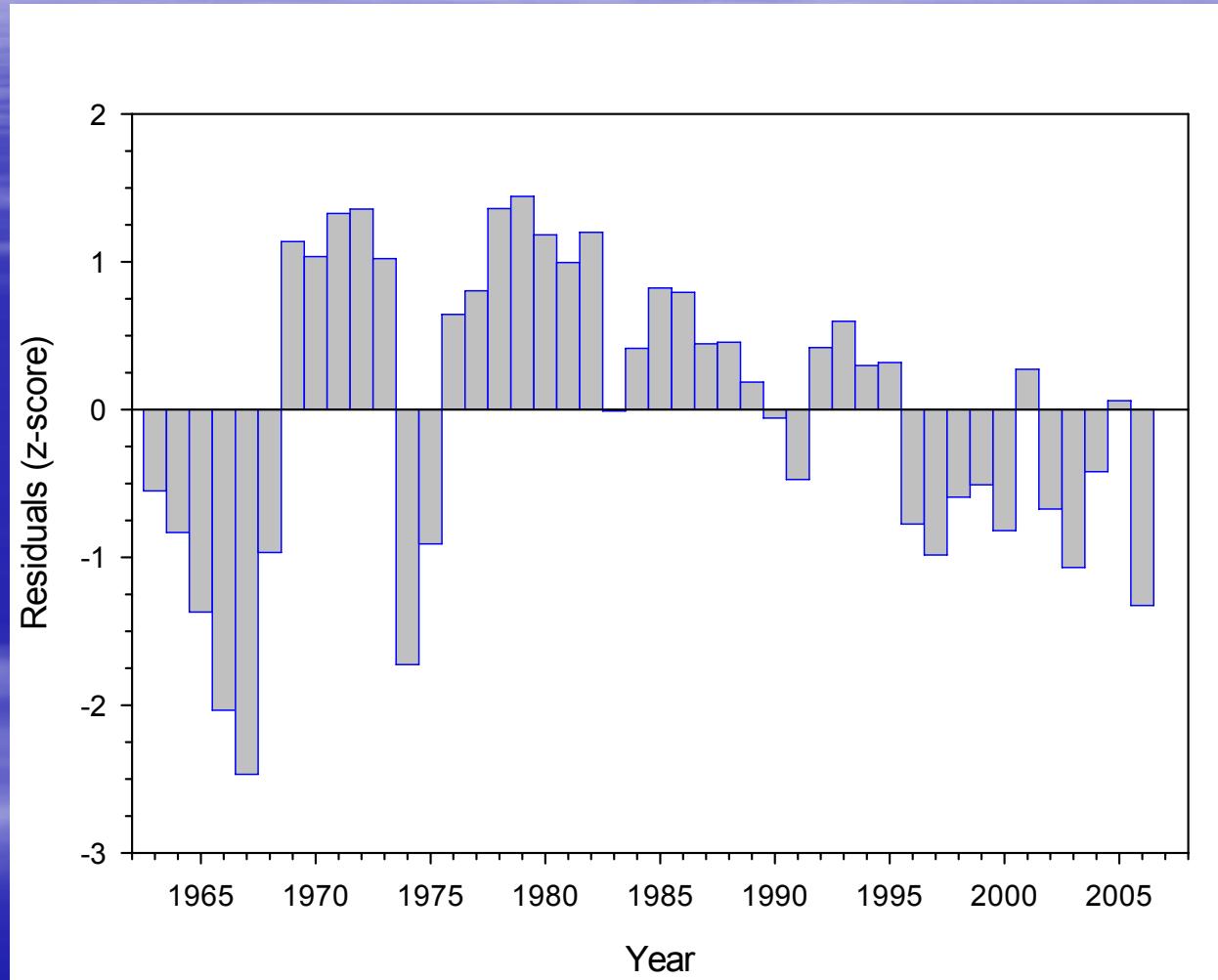
## Replacement Yield Model (Case 32) Reference Points:

	Threshold	Target	Current Estimate	% Threshold
Fishing mortality	0.003	n/a	0.0022	75%
Stock biomass	75,000 mt	150,000 mt	21,200 mt	28%

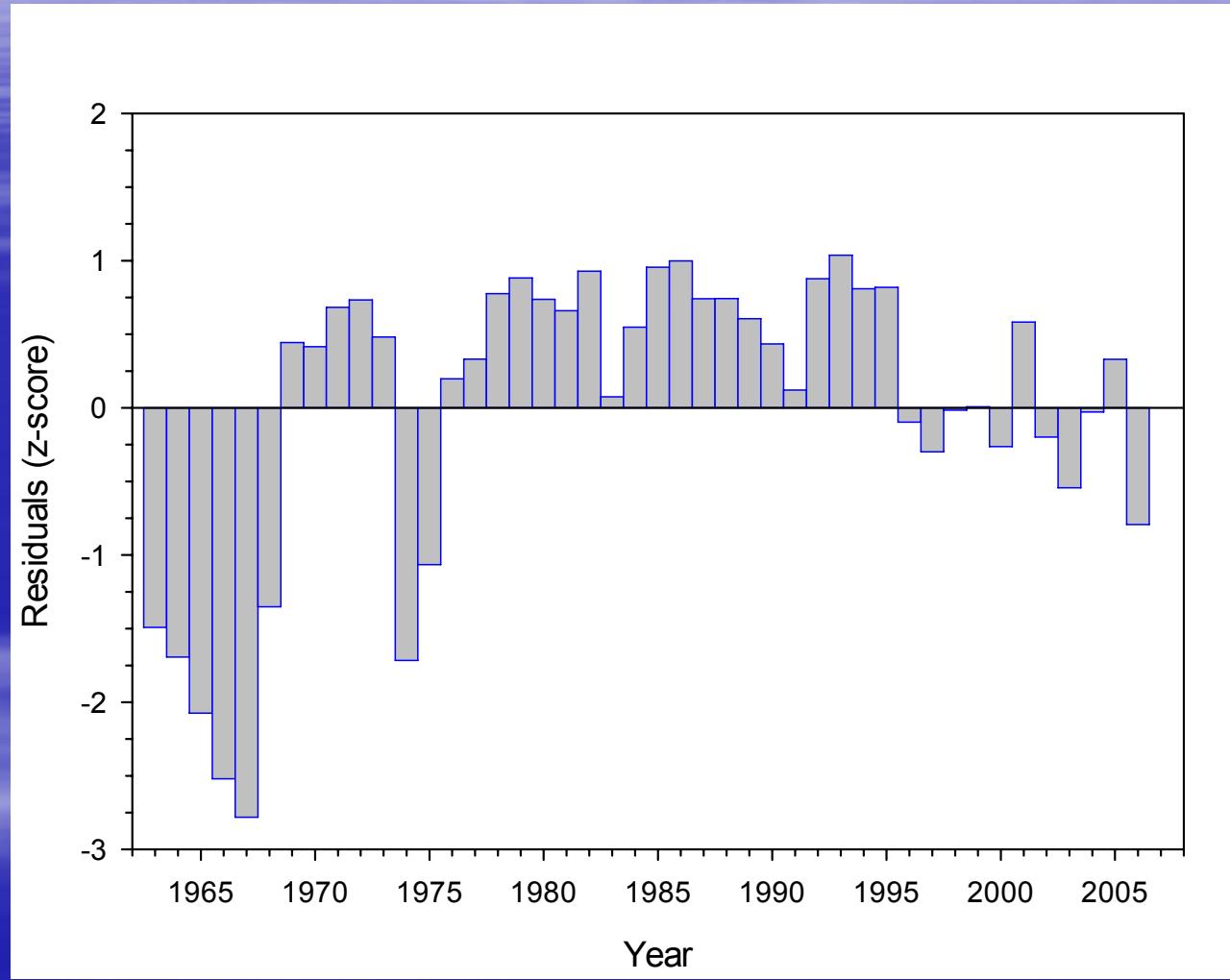
## Replacement Yield Model (Case 24) Reference Points:

	Threshold	Target	Current Estimate	% Threshold
Fishing mortality	0.018	n/a	0.024	128%
Stock biomass	50,000 mt	100,000 mt	2,009 mt	4%

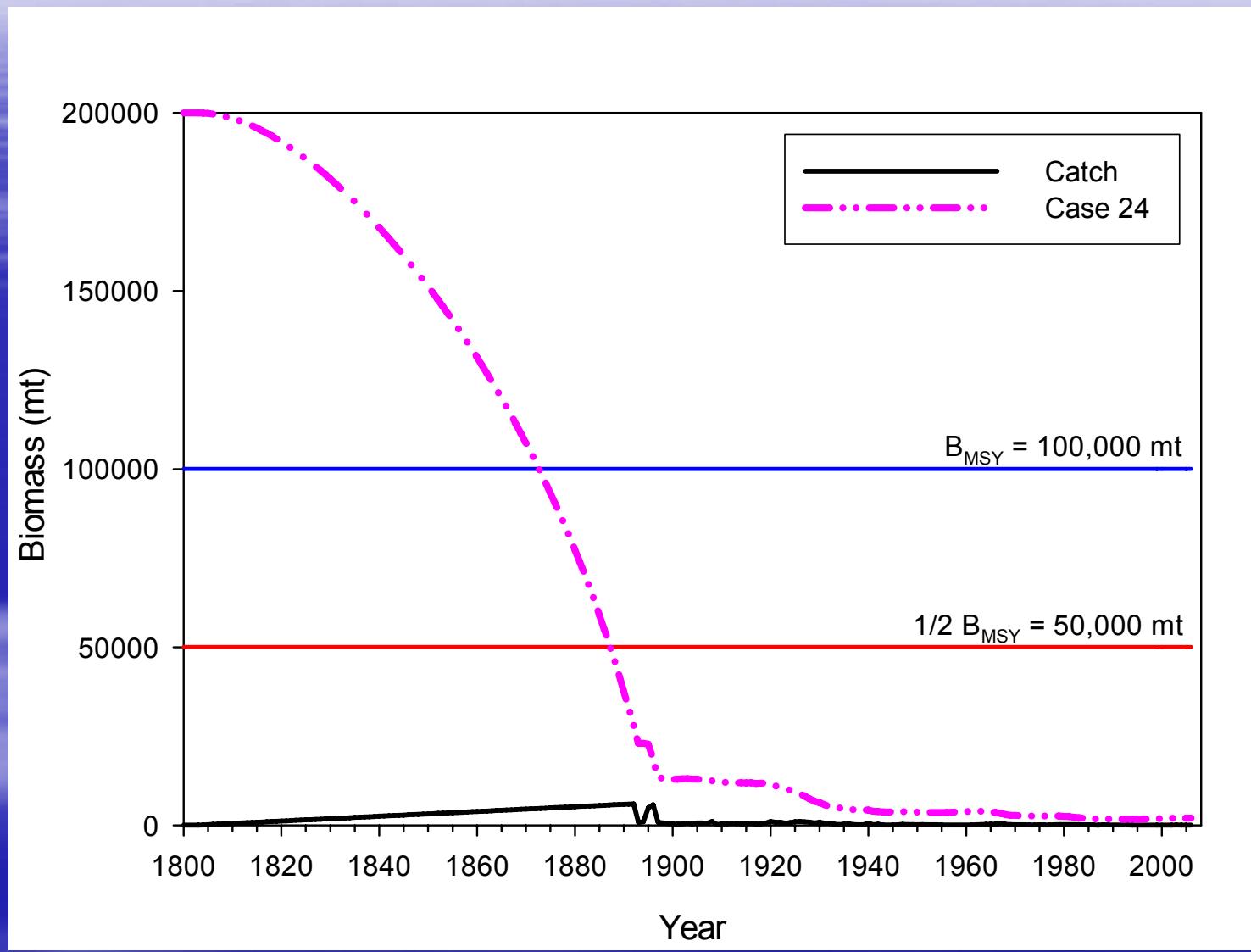
# Residuals for Case 32



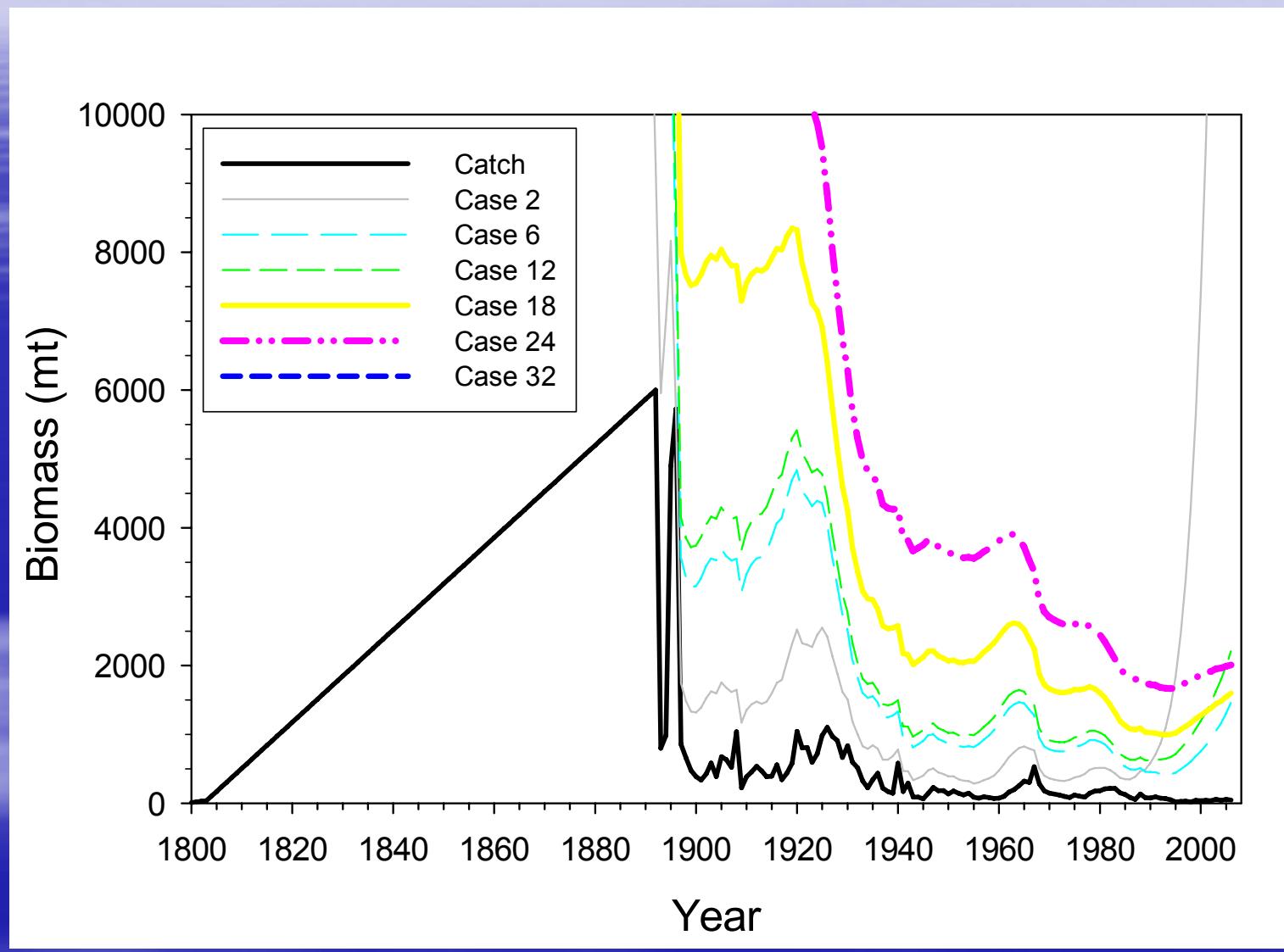
# Residuals for Case 24



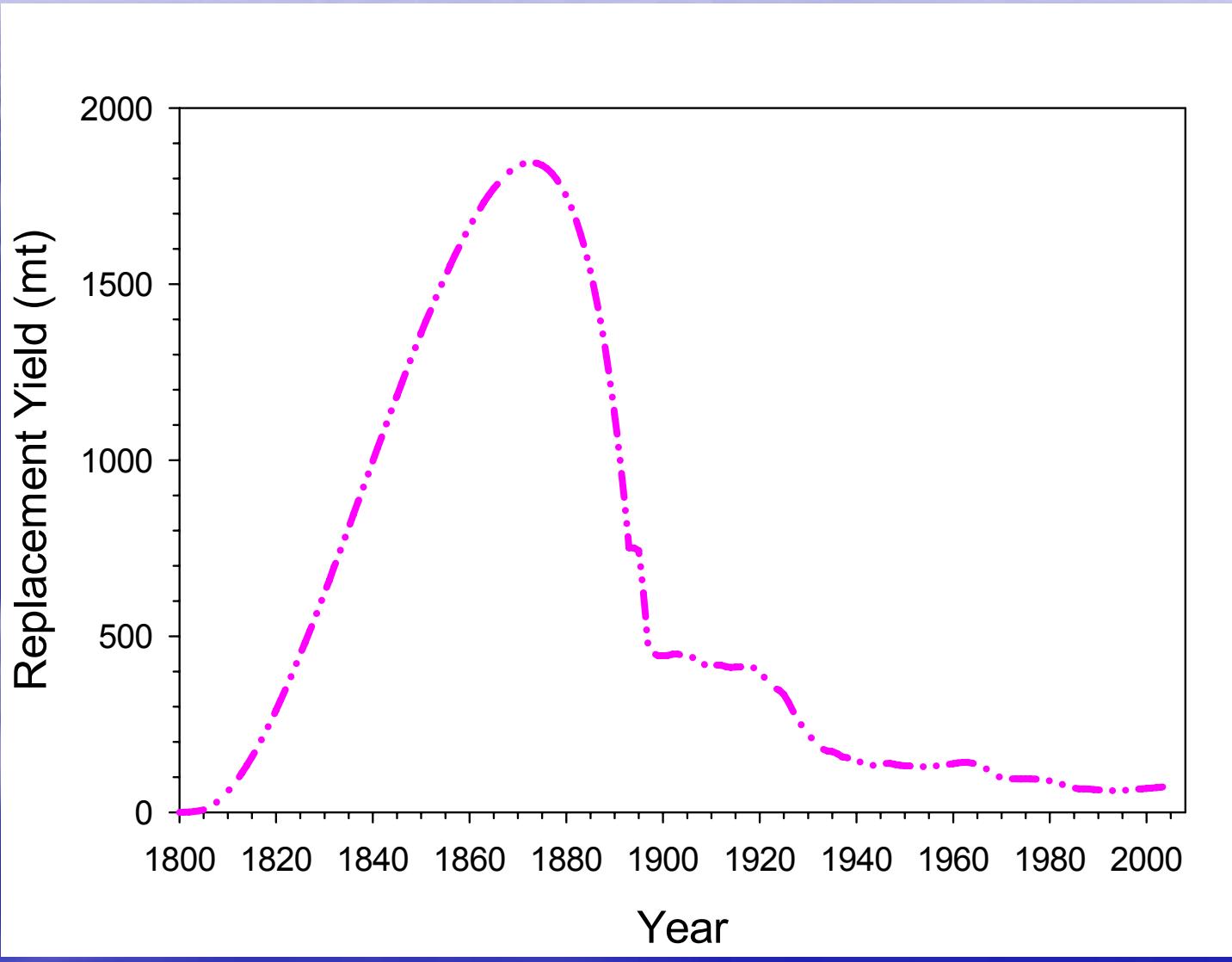
## Biomass for Case 24



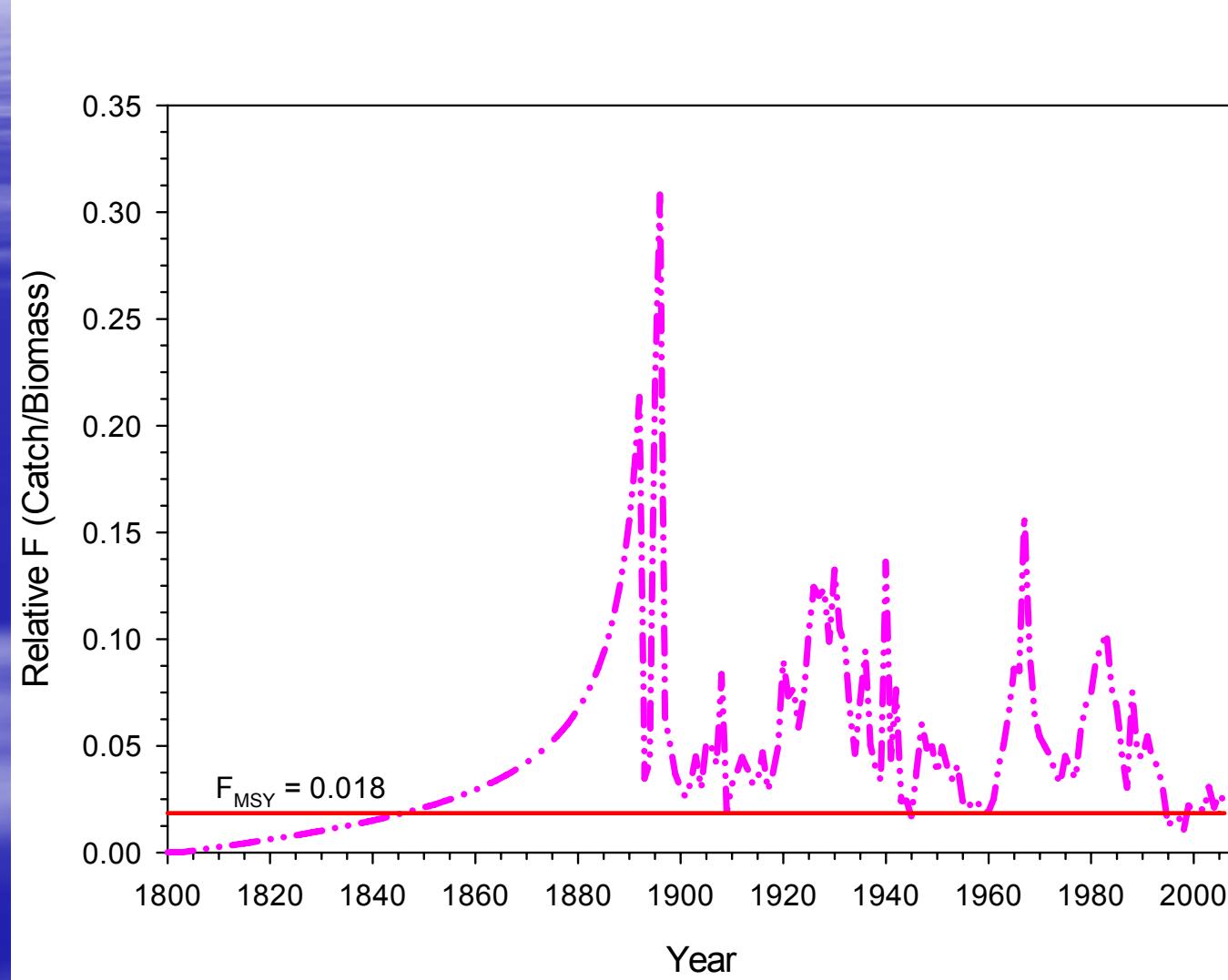
# Replacement Yield Model Biomass



# Replacement Yield Case 24

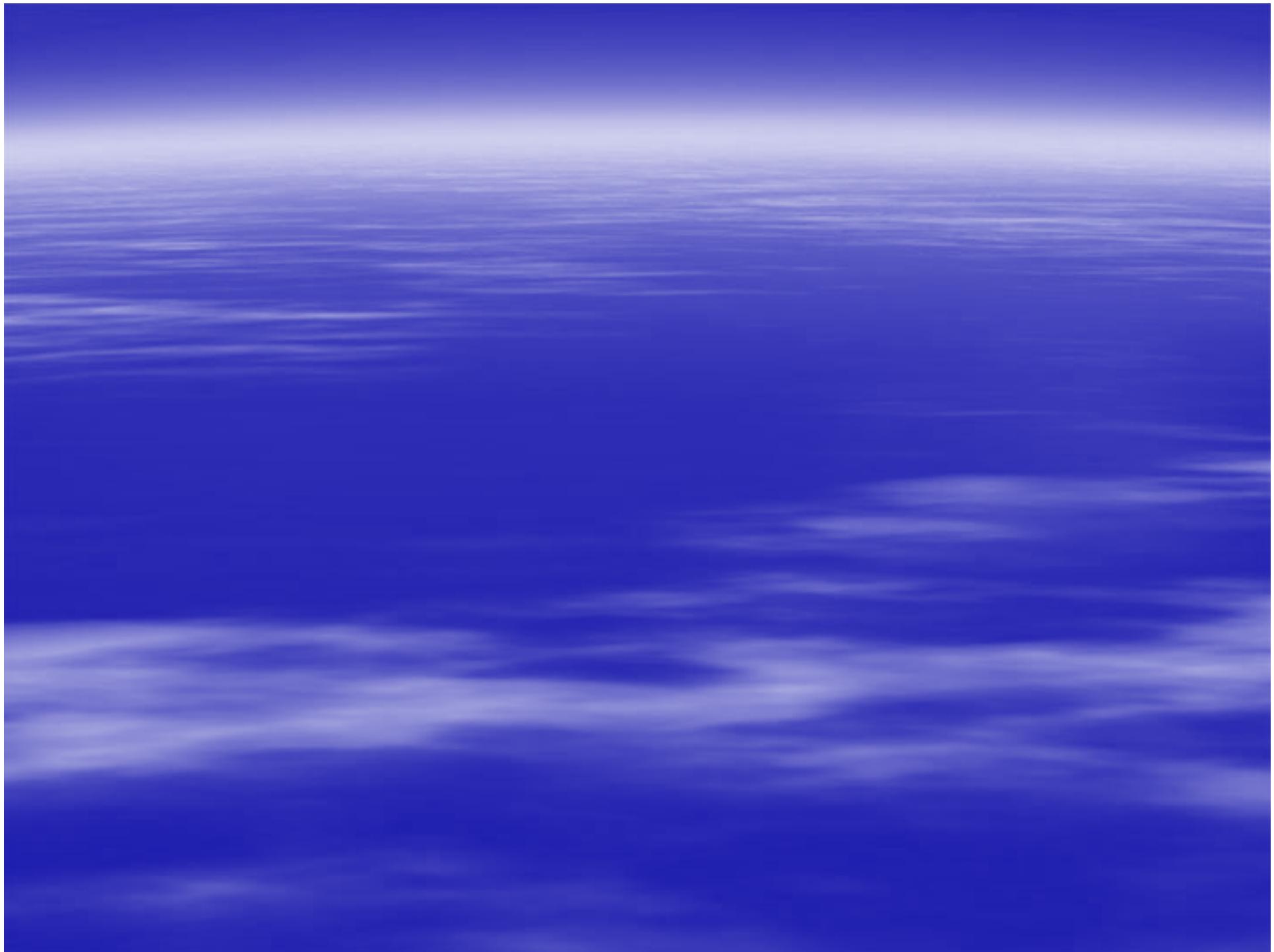


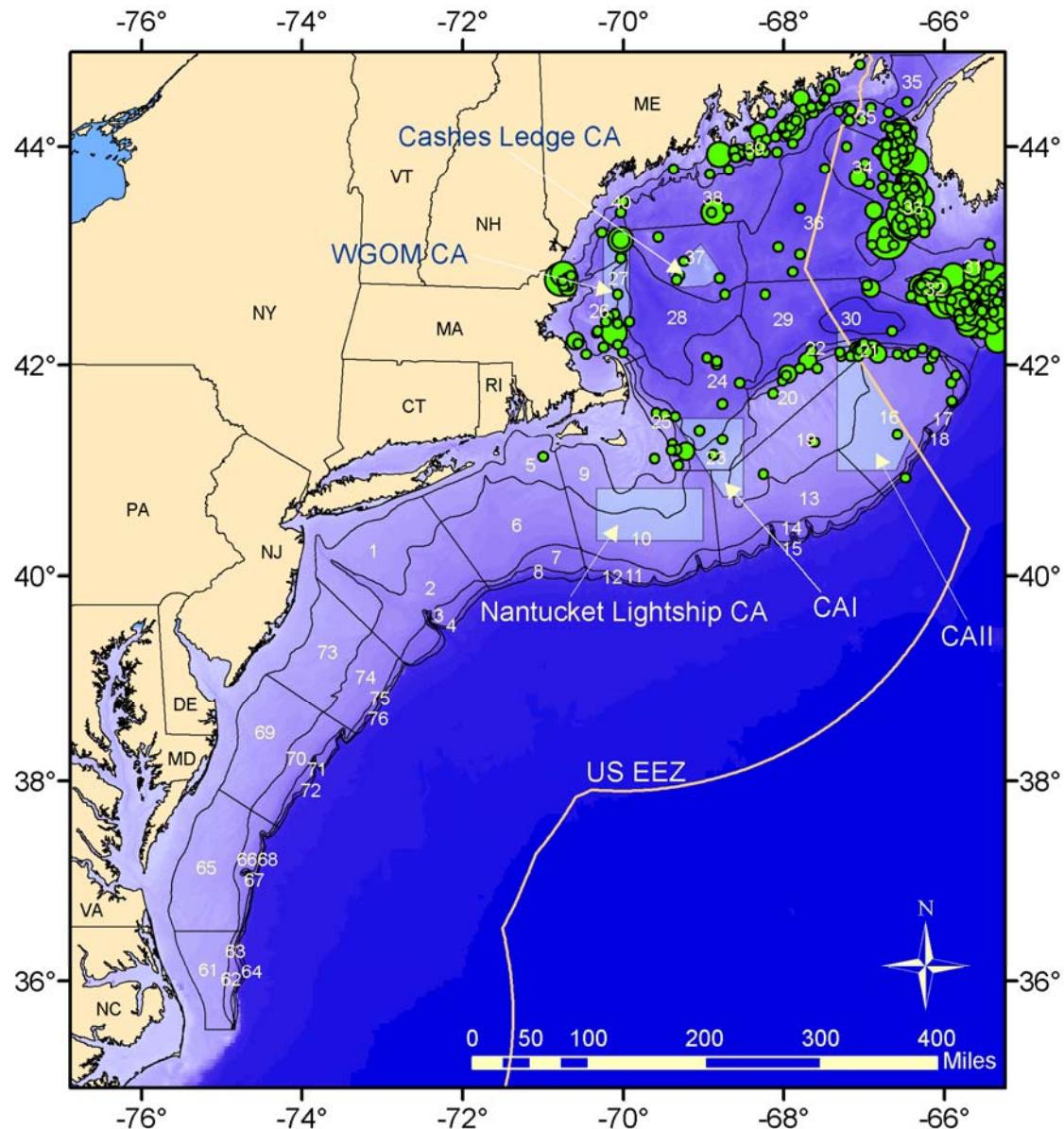
# Fishing Mortality Case 24

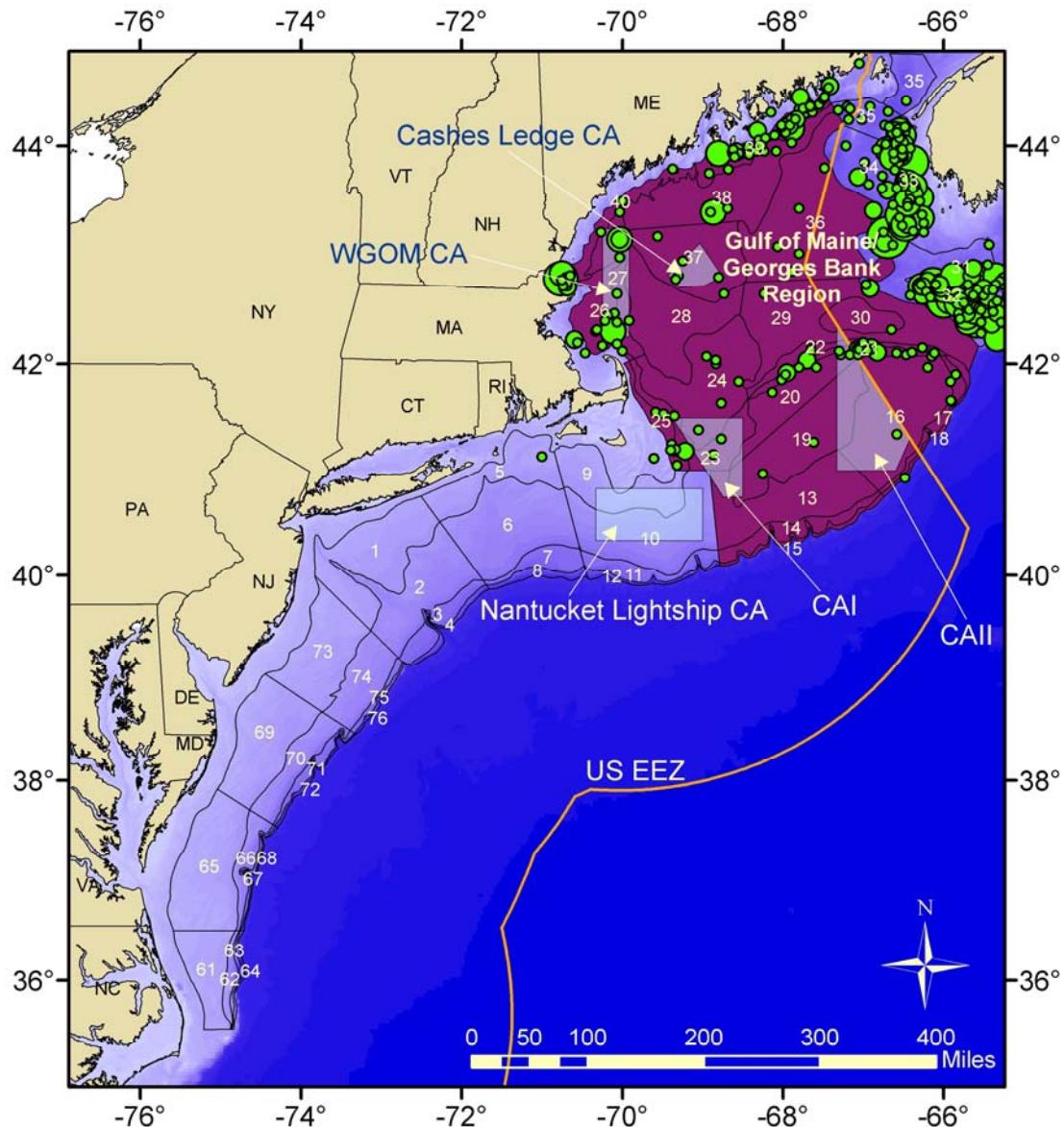


# Replacement Yield Model Simulations

	Case 1	Case 2	Case 3				
K	50000	50000	50000				
r	<b>0.353807079975544</b>	<b>0.353807079975545</b>	<b>0.353807079975546</b>				
B2006 as % of K	0.0%	55.4%	87.5%				
-ln L	19201.398	<b>141.895</b>	198.056				
q	128.790	0.306	0.182				
sigma	0.6	0.6	0.6				
penalty	17508.2800	0.0376	0.1010				
Fmsy	0.1769	0.1769	0.1769				
1/2 Brmsy	12500	12500	12500				
F2006/Fmsy	26907.4651	0.0097	0.0062				
B2006/(1/2 Brmsy)	8.0000E-07	2.2177	3.4983				
	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	
K	90000	90000	90000	90000	90000	90000	
r	<b>0.16307849140</b>	<b>0.16307849145</b>	<b>0.16307849150</b>	<b>0.16307849155</b>	<b>0.16307849160</b>	<b>0.16307860000</b>	
B2006 as % of K	0.0%	0.7%	1.6%	2.5%	3.4%	96.8%	
-ln L	805.999	23.482	<b>22.557</b>	25.079	28.249	65.574	
q	2.089	0.547	0.439	0.380	0.341	0.011	
sigma	0.6	0.6	0.6	0.6	0.6	0.6	
penalty	202.5252	0.0022	0.0037	0.0143	0.0252	0.2392	
Fmsy	0.0815	0.0815	0.0815	0.0815	0.0815	0.0815	
1/2 Brmsy	22500	22500	22500	22500	22500	22500	
F2006/Fmsy	58377.1139	0.9201	0.4010	0.2579	0.1908	0.0067	
B2006/(1/2 Brmsy)	4.4444E-07	0.0282	0.0647	0.1006	0.1360	3.8731	
	Case 10	Case 11	Case 12	Case 13	Case 14	Case 15	Case 16
K	100000	100000	100000	100000	100000	100000	
r	<b>0.139766823</b>	<b>0.139766824</b>	<b>0.139766825</b>	<b>0.139766826</b>	<b>0.139766827</b>	<b>0.139766828</b>	<b>0.13977</b>
B2006 as % of K	0.0%	0.2%	2.2%	4.2%	6.1%	7.9%	98.8%
-ln L	2888.269	34.087	<b>22.373</b>	29.172	35.703	41.399	16.912
q	22.308	0.615	0.335	0.260	0.219	0.191	0.005
sigma	0.6	0.6	0.6	0.6	0.6	0.6	0.6
penalty	1225.5960	0.0132	0.0272	0.0577	0.0792	0.0953	0.2451
Fmsy	0.0699	0.0699	0.0699	0.0699	0.0699	0.0699	0.0699
1/2 Brmsy	25000	25000	25000	25000	25000	25000	
F2006/Fmsy	68113.8160	3.7613	0.3085	0.1636	0.1126	0.0865	0.0069
B2006/(1/2 Brmsy)	4.0000E-07	0.0072	0.0883	0.1665	0.2420	0.3149	3.9524
	Case 17	Case 18	Case 19	Case 20	Case 21	Case 22	
K	150000	150000	150000	150000	150000	150000	
r	<b>0.0708170</b>	<b>0.0708175</b>	<b>0.0708180</b>	<b>0.0708185</b>	<b>0.0708190</b>	<b>0.0720000</b>	
B2006 as % of K	0.0%	1.1%	2.2%	3.3%	4.4%	96.9%	
-ln L	862.258	<b>15.744</b>	15.858	18.157	20.515	8.797	
q	1.389	0.231	0.164	0.130	0.110	0.003	
sigma	0.6	0.6	0.6	0.6	0.6	0.6	
penalty	200.7897	0.0726	0.1130	0.1365	0.1524	0.2474	
Fmsy	0.0354	0.0354	0.0354	0.0354	0.0354	0.0360	
1/2 Brmsy	37500	37500	37500	37500	37500	37500	
F2006/Fmsy	134431.7278	0.8406	0.4040	0.2679	0.2015	0.0091	
B2006/(1/2 Brmsy)	2.66667E-07	0.0426	0.0887	0.1338	0.1779	3.8764	
	Case 23	Case 24	Case 25	Case 26	Case 27	Case 28	
K	200000	200000	200000	200000	200000	200000	
r	<b>0.0368</b>	<b>0.0369</b>	<b>0.037</b>	<b>0.0371</b>	<b>0.0372</b>	<b>0.045</b>	
B2006 as % of K	0.0%	1.0%	7.8%	13.8%	19.0%	93.2%	
-ln L	168917325.973	<b>13.800</b>	15.152	16.674	17.078	8.782	
q	12997.220	0.149	0.036	0.022	0.016	0.002	
sigma	0.6	0.6	0.6	0.6	0.6	0.6	
penalty	168916733.9256	0.1234	0.2150	0.2288	0.2346	0.2480	
Fmsy	0.0184	0.0185	0.0185	0.0186	0.0186	0.0225	
1/2 Brmsy	50000	50000	50000	50000	50000	50000	
F2006/Fmsy	258697.0562	1.2845	0.1659	0.0931	0.0667	0.0113	
B2006/(1/2 Brmsy)	2.0000E-07	0.20000E-07	0.3101	0.5511	0.7675	3.7295	
	Case 29	Case 30	Case 31	Case 32	Case 33	Case 34	Case 35
K	300000	300000	300000	300000	300000	300000	
r	<b>0.003</b>	<b>0.004</b>	<b>0.005</b>	<b>0.006</b>	<b>0.007</b>	<b>0.008</b>	<b>0.030</b>
B2006 as % of K	0.0%	1.1%	3.9%	7.1%	10.7%	14.8%	92.3%
-ln L	18555487.020	12.982	9.242	<b>8.935</b>	8.948	9.029	8.593
q	4307.755	0.071	0.027	0.016	0.011	0.008	0.001
sigma	0.6	0.6	0.6	0.6	0.6	0.6	0.6
penalty	18554249.0505	0.1841	0.2236	<b>0.2342</b>	0.2391	0.2418	0.2487
Fmsy	0.0015	0.0020	0.0025	<b>0.0030</b>	0.0035	0.0040	0.0150
1/2 Brmsy	75000	75000	75000	<b>75000</b>	75000	75000	75000
F2006/Fmsy	3173350.5555	7.1393	1.6432	0.7478	0.4222	0.2673	0.0115
B2006/(1/2 Brmsy)	1.3333E-07	0.0444	0.1545	0.2829	0.4295	0.5936	3.6913







NEFSC survey strata used to define the Gulf of Maine/Georges Bank region of the Atlantic halibut stock.

# Atlantic Halibut Current Status and Management

## Current Status

- NEFSC: Overfished, Overfishing can not be determined
- NOAA: Species of Concern
- American Fisheries Society: Threatened
- IUCN: Endangered (due to overfishing)

## Management

- Northeast Multispecies Fishery Management Plan (Amendment 9) 1999
- 1 fish halibut possession limit per trip for commercial and recreational vessels
- Minimum size of 36 inches (91 cm)

# 2000-2004 Experimental Halibut Fishery

## Maine DMR and Maine Sea Grant

- Tagged 825 halibut in coastal Maine waters
- 1,611 fish retained, otoliths and gonad samples taken
- 92 recaptured as of Dec. 31, 2005 (11% return rate)
- 28% of recaptures in Canadian waters
- Mean days at large = 431
- Mean distance traveled = 151 km (1,758 km max)
- Mean length of tagged halibut = 79 cm (all immature)

# Basic Life History Characteristics for Atlantic Halibut

Sigourney et. al. 2006

- Aged 530 otoliths from NMFS surveys and Experimental Halibut fishery
- Halibut up to ~40+ years old
- Longline gear selected fish with faster growth compared to bottom trawl
- $A_{50} = 6.0$  years for males, 7.3 years for females
- $L_{50} = 80.2$  cm for males, 103.0 cm for females

# Stock Reduction Analysis

## Kimura and Tagart, 1982

- Uses available time series of catch data:  $C_i$  (catch in year  $i$ )

- For  $i = 1, \dots, n$  catch equations:

$$C_i = B_i F_i (1 - \exp(-F_i - M)) / (F_i + M)$$

$$B_i = B_{i-1} \exp(-F_{i-1} - M) + R \text{ for } i > 1$$

- Provide starting estimates for:  $B_1$  and  $M$ , solve for  $R$

- Find best estimates of  $F_i$ ,  $B_i$

- Two equations used for SRA plots:

$$P = B_{n+1}/B_1$$

describes the decline in population biomass caused by  $n$  years of catches

- Expected recruitment line (for varying values of  $R$  and  $B_1$ ):

$$R = B_1(1 - \exp(-M))$$

# Stock Reduction Analysis

## Strengths

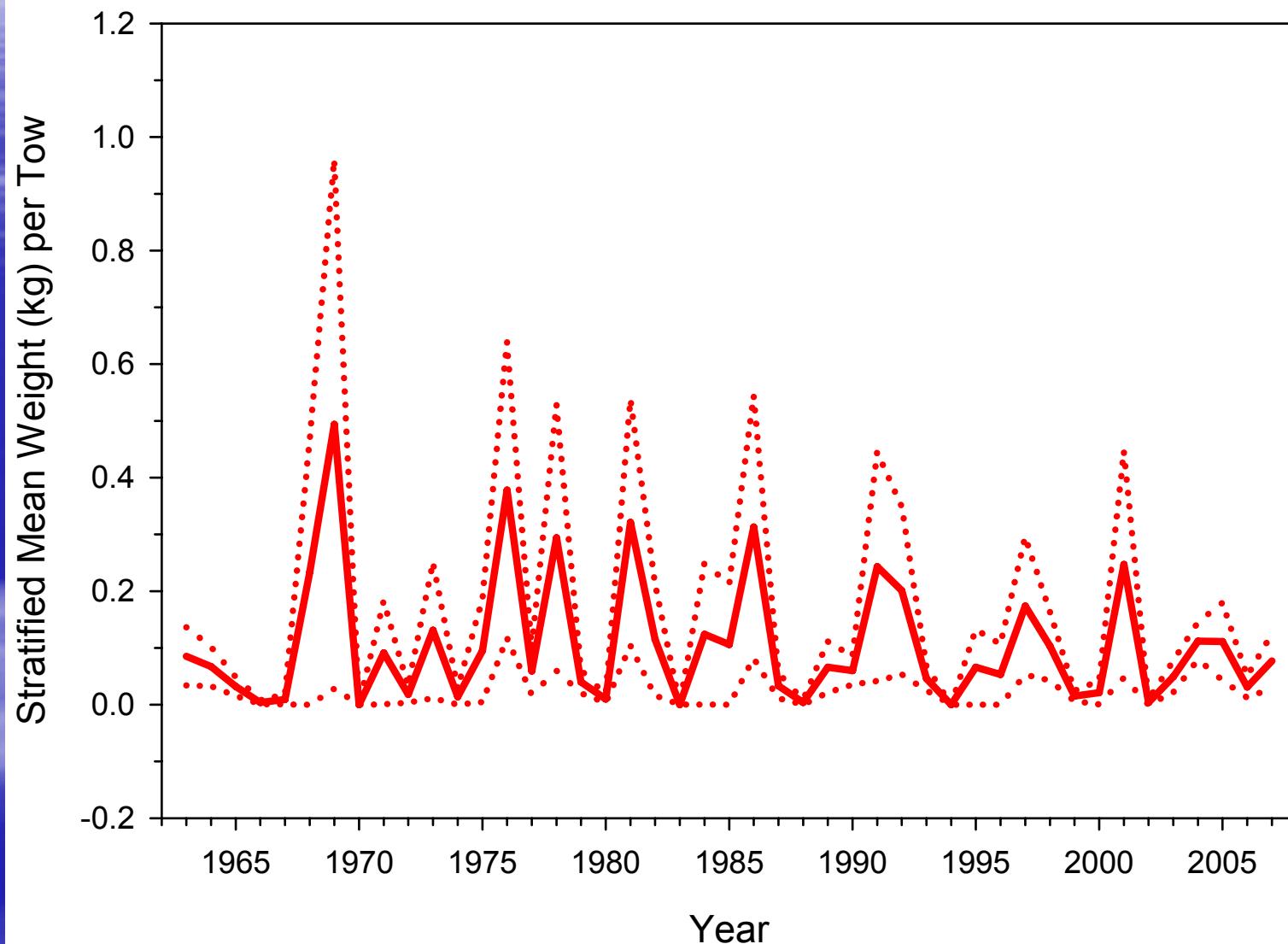
- Uses entire catch time series
- Does not rely on surveys (little relation to catches and high uncertainty)
- Very simplistic, no age data required
- Provide annual estimates of F (possibly use to determine overfishing status)
- Immigration or emigration do not violate assumptions of model
  - included in apparent recruitment
- Plots can be used to verify results in relation to other indices/known values
  - Compare to NMFS survey indices, future inshore Maine halibut longline surveys etc.

# Stock Reduction Analysis

## Weaknesses

- Not widely used for stock assessments
- Current regulations could skew catch in recent years
  - Incorporate discards?
- Starting estimates very rough for  $B_i, F_1, \dots, F_n, M, P$
- $M$  and  $R$  are fixed through time
  - $R$  can be variable in more complex versions of the model
- Current model assumes virgin biomass for  $B_i$ 
  - might be possible include  $F$  in initial biomass
- Are assumptions/problems with this approach worse than the fall-back?
  - Any better alternatives?

Atlantic halibut NEFSC autumn biomass indices  
(stratified mean weight per tow) with 1 standard error



Atlantic halibut NEFSC spring biomass indices  
(stratified mean weight per tow) with 1 standard error

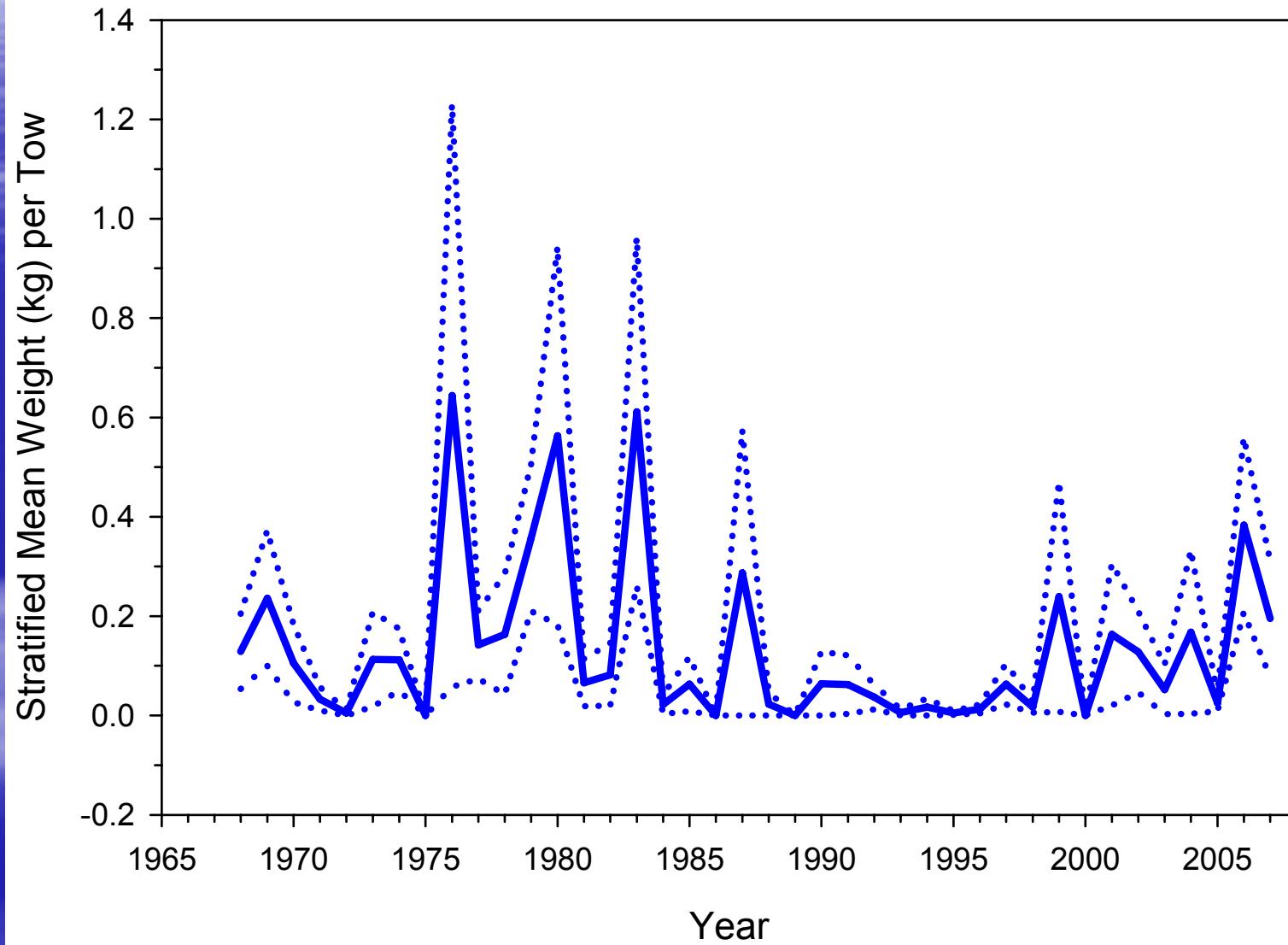
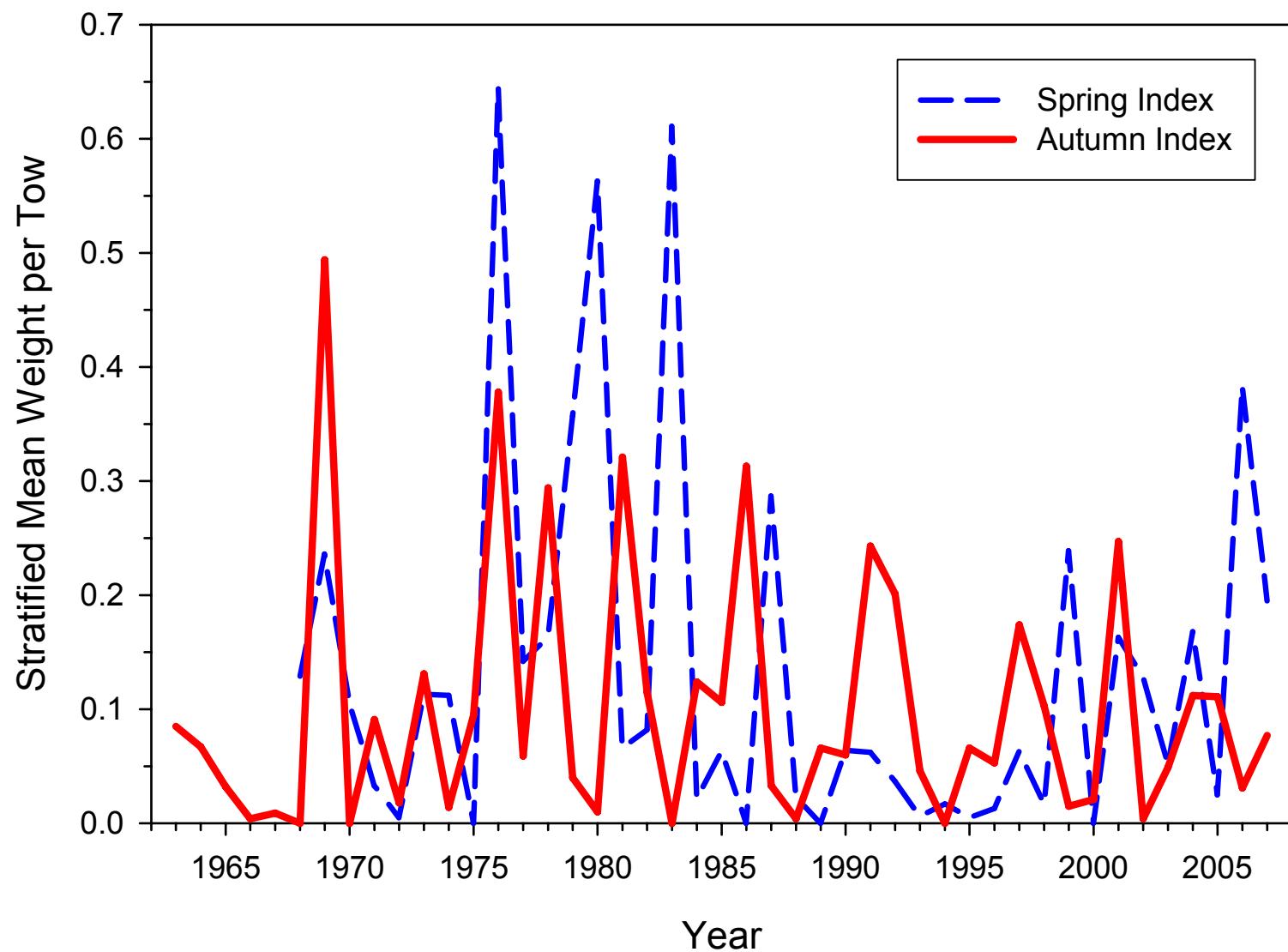


Figure S3. Atlantic halibut biomass indices (stratified mean weight per tow) from NEFSC spring and autumn surveys.



# Use of Spring v. Autumn Survey Index

## Time Series

- Autumn survey has longer time series
- Autumn survey includes relatively high landings during 1963-1967 (highest landings since 1930s)

## Variability

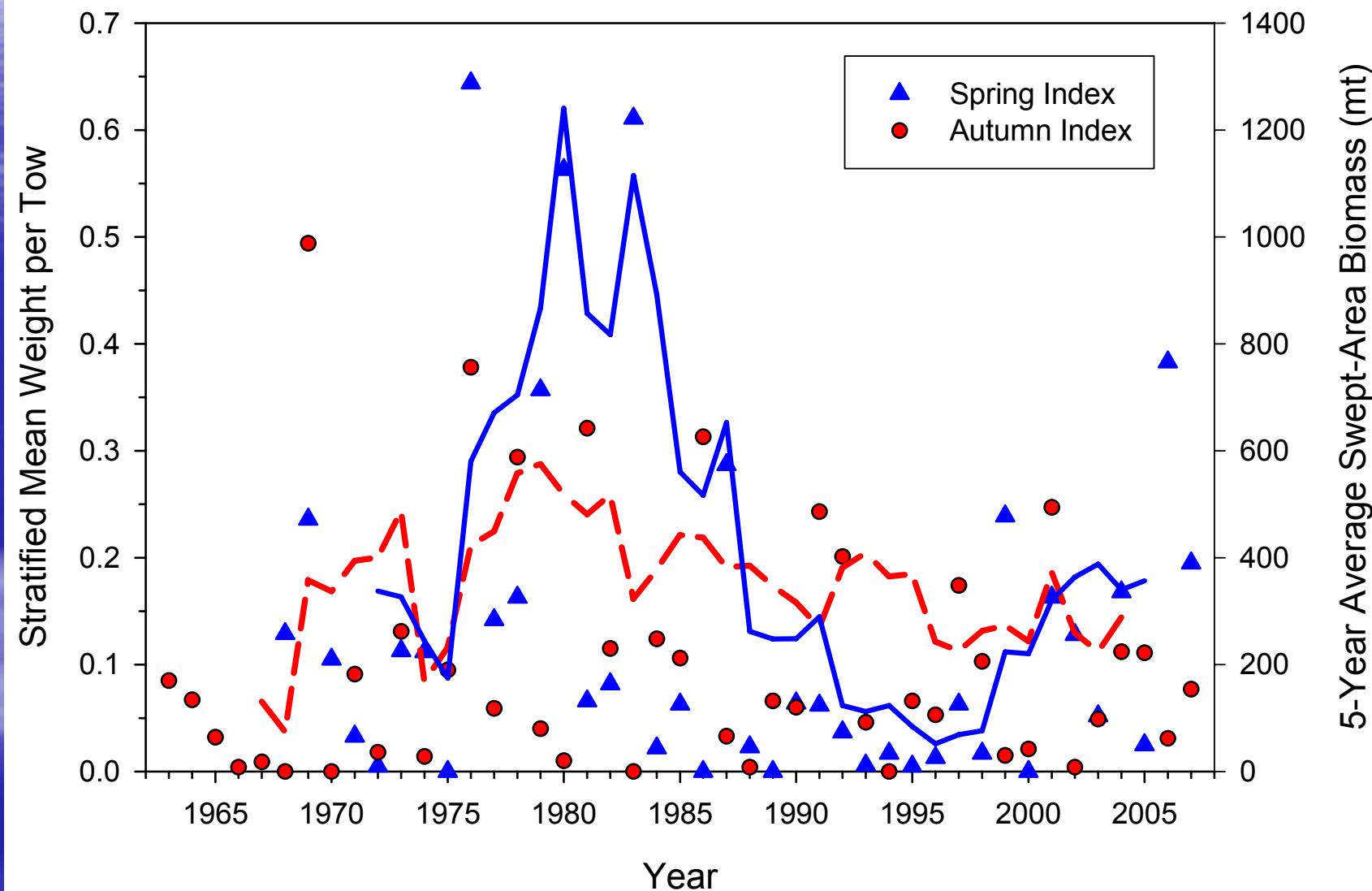
- CVs/SE similar between surveys
- Similar number of years with 0 halibut
- Similar number of total halibut caught

## Temperature Correlation in Spring Survey

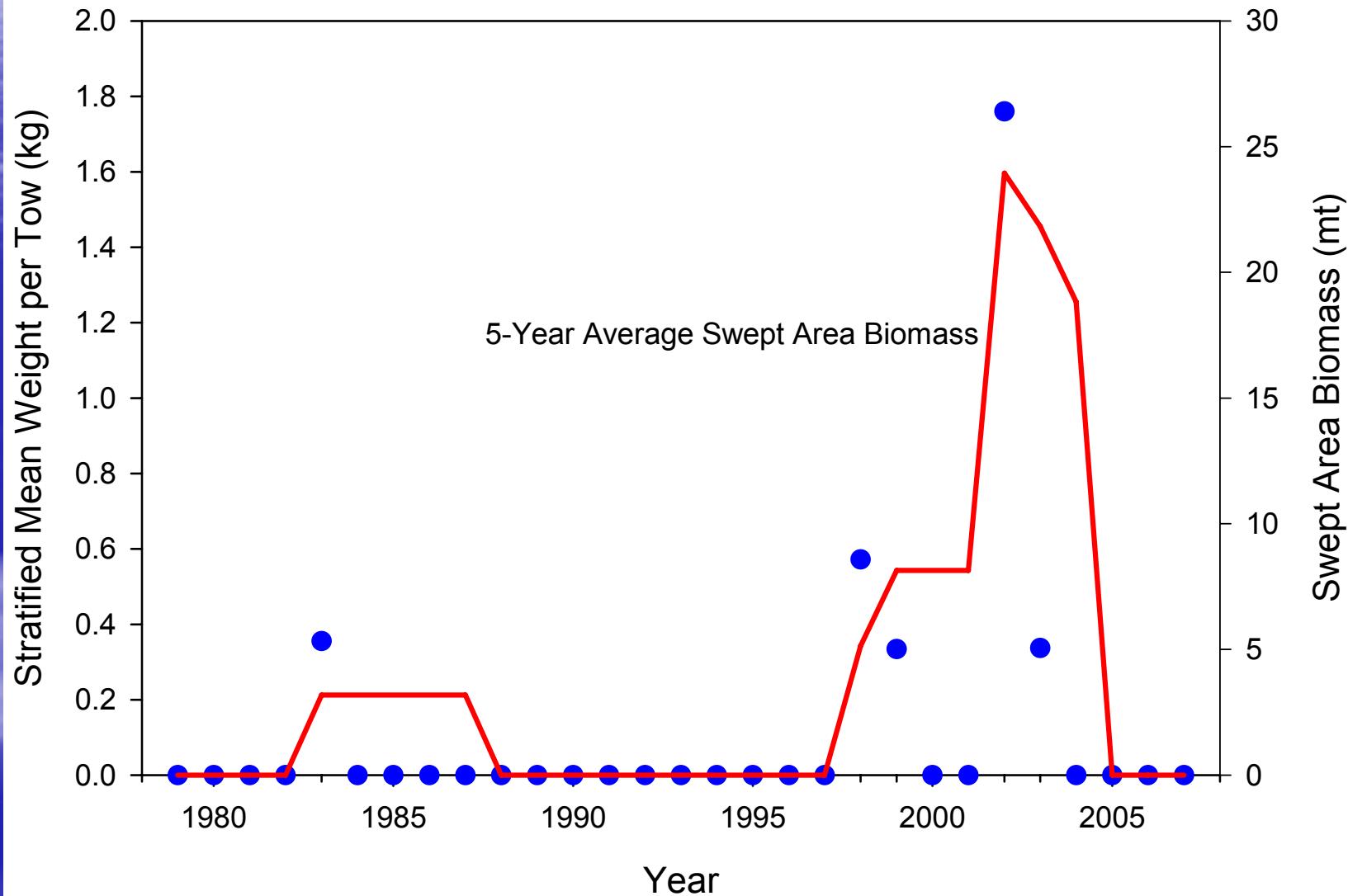
- Spring swept-area biomass neg. corr. with spring bottom water temperature anomalies
- Water temp. influences spring distribution
  - Not seen in autumn survey

## Atlantic Halibut

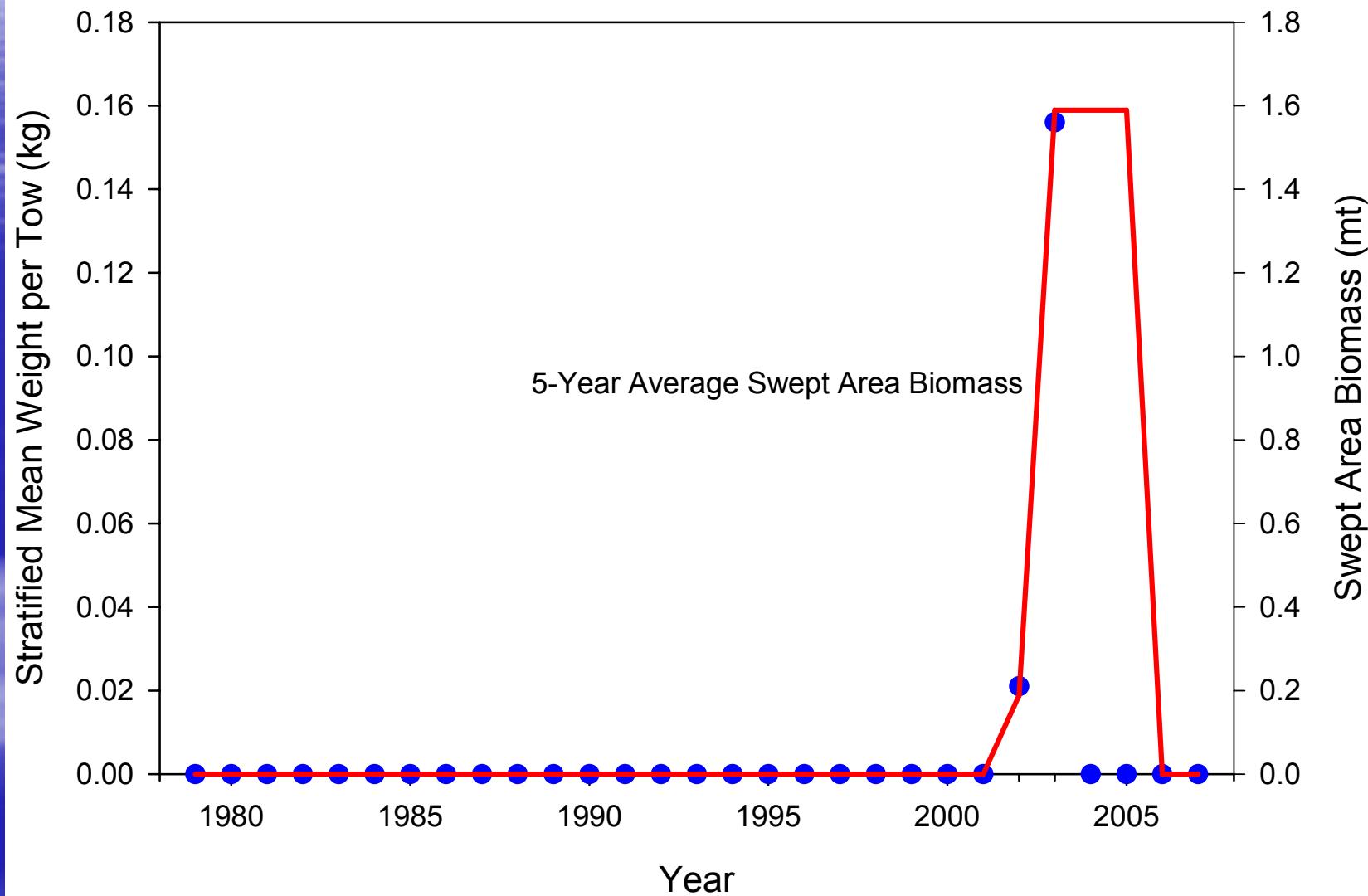
### NEFSC Spring and Autumn Survey Indices and Swept-Area Biomass



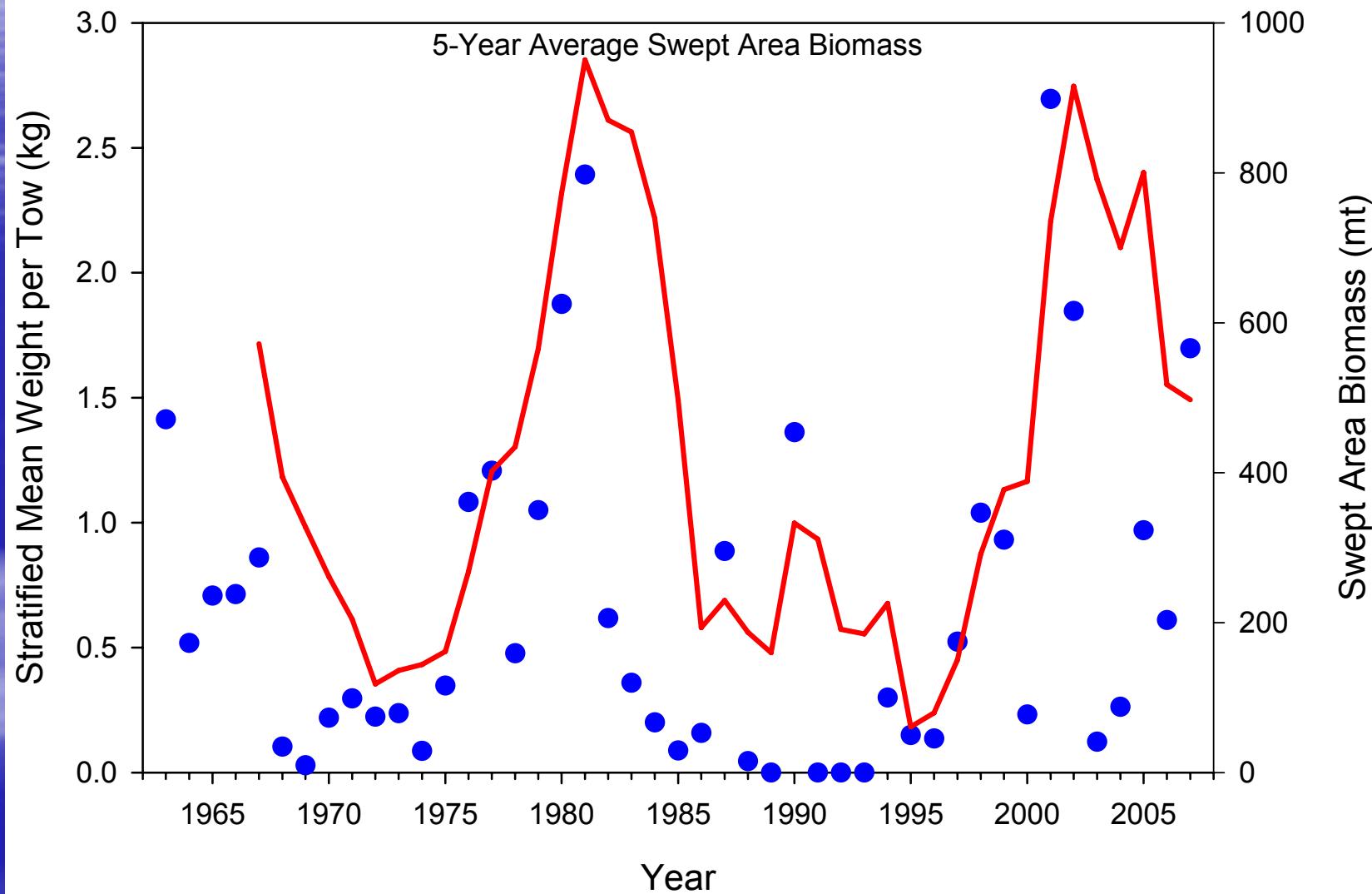
## NMFS Fall Survey Halibut in Massachusetts Inshore Strata



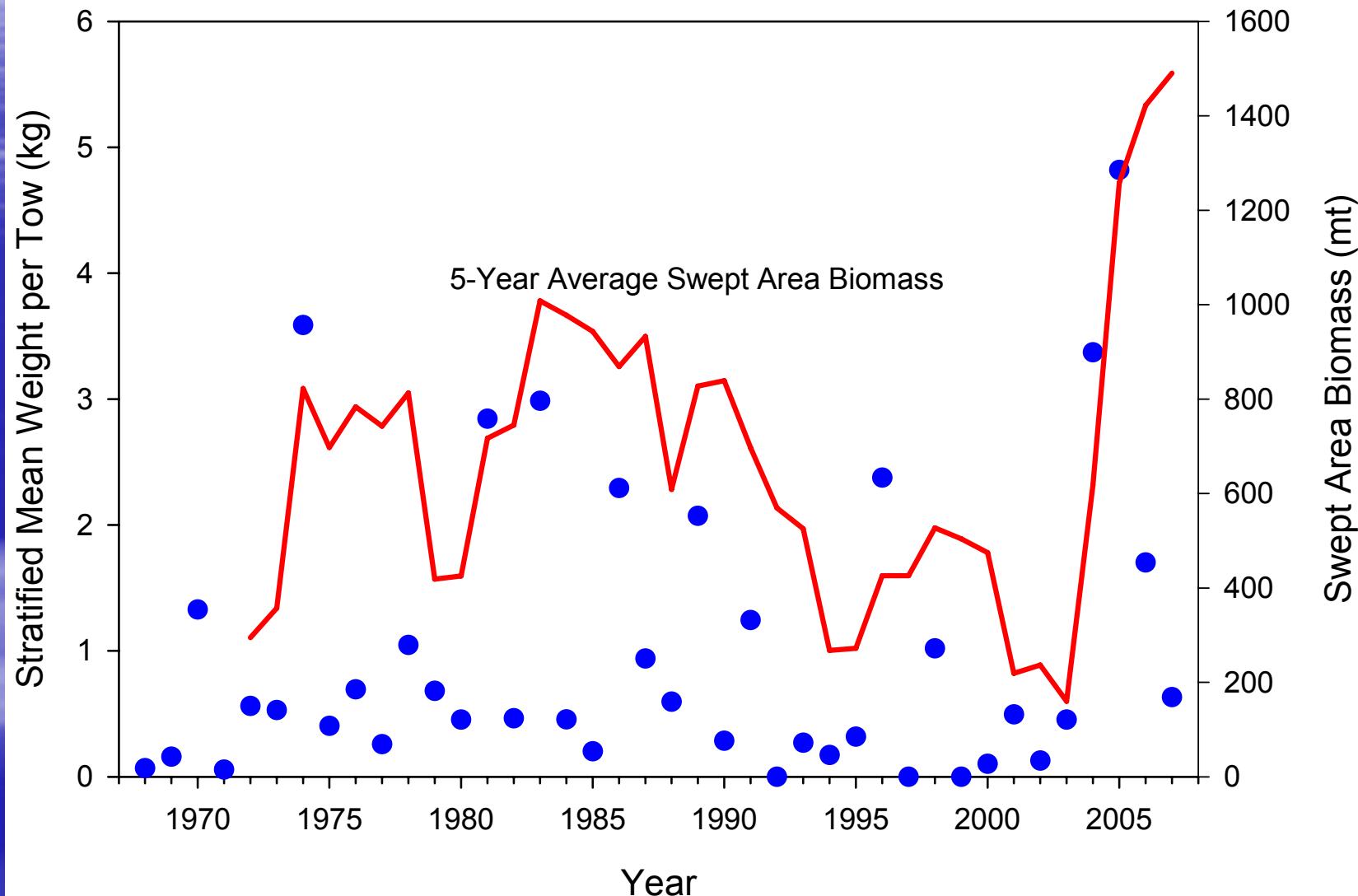
## NMFS Spring Survey Halibut in Massachusetts Inshore Strata



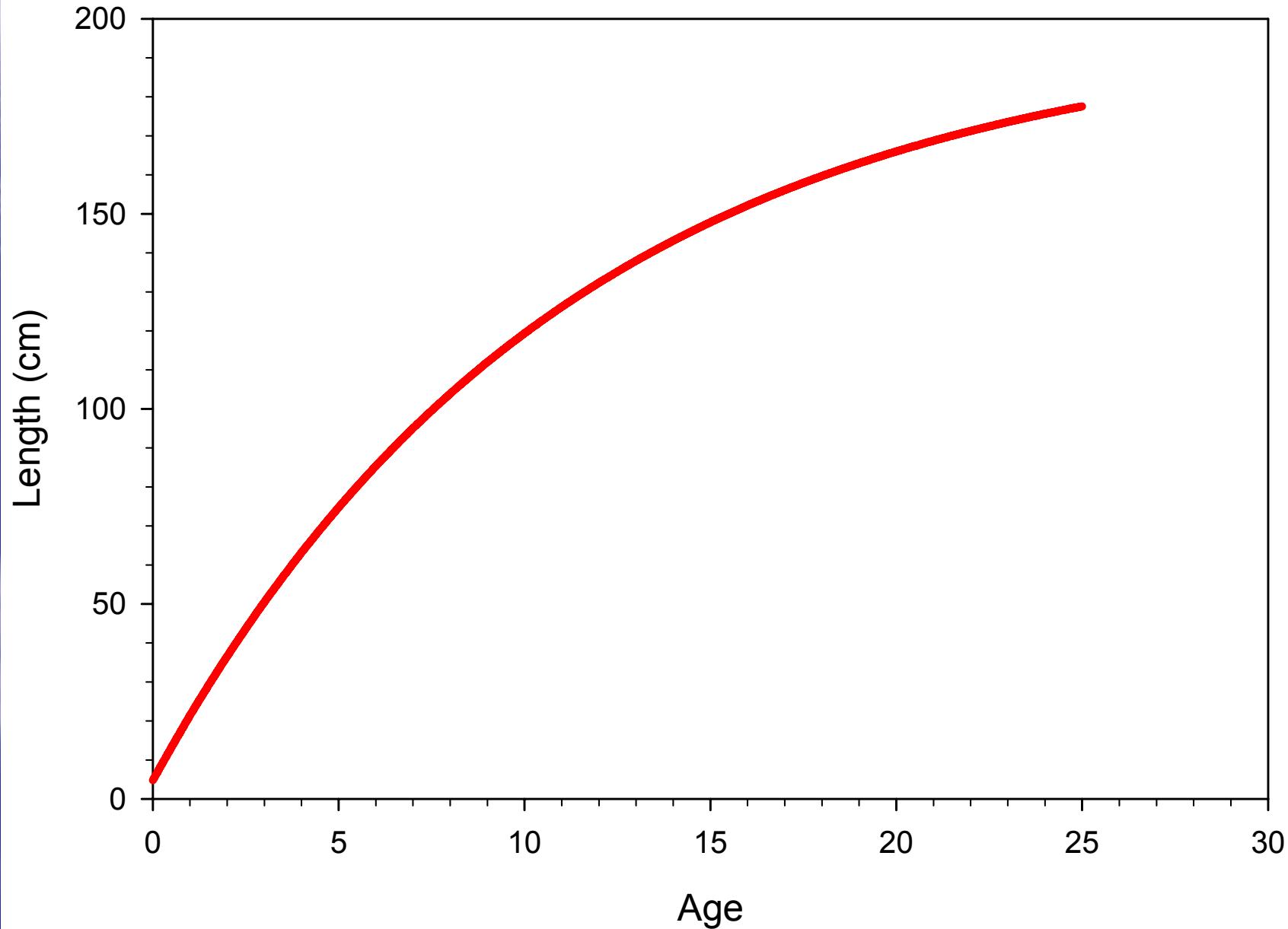
## NMFS Fall Survey Scotian Shelf Halibut



## NMFS Spring Survey Scotian Shelf Halibut



## Halibut von Bertalanffy Growth Curve Pooled Data Males



### Atlantic Halibut

	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	D
Landings	●	●	●	●	●	●	●	●	●	○	○	○	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	5.616			
Discards																																						10.444								
Autumn Survey Exploitation Index						●	●	●	●	●	○	●	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	17.244						
NEFSC Autumn Survey	○	○	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	7.313							
NEFSC Spring Survey											●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	6.834					
Autumn Survey 5 Year Average Swept-Area Biomass						●	●	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	1.399		

Legend

● Highest   ● 2nd Highest   ○ Middle   ● 2nd Lowest   ● Lowest

D = Measure of Dispersion: Range/Median